EFFECT OF SLAG ON STRENGTH AND HYDRAULIC PROPERTIES OF LIME STABILIZED POND ASH

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology
In
Civil Engineering
(Geotechnical Engineering)

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Under The Guidance of
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CERTIFICATE

This is to affirm that the thesis entitled, “**Effect of Slag on Strength And Hydraulic Properties of Lime Stabilized Pond Ash**” submitted by **T. Raj Priyanka** in partial fulfillment of the requirement for the award of **Master of Technology** degree in **Civil Engineering** with specialization in **Geotechnical Engineering** at the National Institute of Technology Rourkela is an authentic work carried out by her under our supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Place: Rourkela

Date:

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Notation	Description
MDD	Maximum Dry Density (g/cc)
OMC	Optimum Moisture Content (%)
UCS	Unconfined Compressive Strength (kPa)
Cu	Coefficient of Uniformity
Cc	Coefficient of Curvature
G	Specific Gravity
k	Coefficient of Permeability (cm/sec)

Abstract

Massive urbanization in the recent times has led a high increase in the power demands and eventually an increase in the production of pond ash generated as a waste material from thermal power plants. To decrease the environmental pollution and hazardous effects, it is imperative to utilize pond ash. But pond ash as such does not have enough strength to be used in civil engineering. So, it is advisable to improve the engineering properties of the pond ash by stabilizing it by adding other materials. In the present study effect of lime and ground granulated blast furnace slag (GGBS) on strength and hydraulic conductivity properties of pond ash are determined. Lime as stabilizing agent in different proportions (0, 3, 6, 9, 15 %) and slag as admixture are added in different proportions (0, 5, 10 and 15%) and the compaction characteristics of the resulted mixture were determined by standard proctor test, strength by Unconfined Compressive Strength test (UCS) and hydraulic conductivity by permeability test. The UCS samples were cured for 0, 3, 7, 14 and 28 days and the strength was determined. The permeability samples are cured for 0, 7, 14 and 28 days. The results showed an increment of maximum dry density and decrease in optimum moisture content with an increasing lime content, slag and curing period. The effect of lime and slag content on the strength and hydraulic properties of the pond ash samples at various curing periods are studied. The results are examined and the optimum percentages of slag required for attaining maximum strength at 3% and 15% lime at different curing periods are reported as the desired proportion for stabilization

CHAPTER 1

INTRODUCTION

1.1 Introduction

Pond ash is a waste material generated as by-product which is the mixture of fly ash and bottom ash transported in slurry form and stored in the lagoons by thermal power plants due to pulverization of coal. The coal ashes considered as an industrial waste can be effectively used in the construction industry. The disposal methods commonly adopted are the dry form or the wet method. In wet method, the ashes and water are mixed and are discharged into water bodies in slurry form called as ash ponds. The disposal of the waste produced by the manufacturing industries in India is one of the greatest challenges faced by them which make this problem complex.

India produces about 180 million metric tons of fly ash every year. The nation uses only about 38 percent of its total fly ash production for cement manufacturing (approximately10.42 million metric tons), land filling, brick manufacturing, mine filling, agriculture and other uses. With the continued reliance on coal, India will have huge supplies of fly ash in the years to come which is estimated to be about 225 million metric tons of fly ash, which has to be stored in more than 1.8 million acres of ponds by 2032.

The thermal power plants and many other industries use coal as the primary fuel in India and and many other countries. More than 270 million tons of fly ash is produced anually in four major countries namely, China, India, Poland, and the United States. Of the total fly ash produced from these countries less than half of it is used in major applications. The coal reserves of India are approximately 200 billion tons which resulted in annual production of 250 million tons. The ash generation has increased to 131 million tons during 2010-11 and is expected to grow further. 112 million tons of fly ash is produced in India which occupies 65000 acre of land. This production is expected to cross 225 million tons by the year 2017.

Fly ash being very light in weight can fly in air causing environmental pollution. It can directly or indirectly cause health hazards. The thermal power plants based on coal are facing serious problems of handling and disposal of the ash produced. The coal in India contains high ash content (30-50%) which makes this problem complex. The major concerns in the thermal power plants are the proper disposal of the ash without affecting the environment. To eradicate these issues, many attempts have been done and are being made to utilize the ash other than dumping it. The coal ash thus produced from thermal plants is in huge quantities and so its massive use has to be adopted to reduce the disposal problems. Hence it is decided to be utilized in various structural and geotechnical engineering applications such as construction of embankments, as a backfill material, as a sub-base material, etc. In this respect, a vigorous study of the properties, namely physical and chemical behavior is required. This urges the need for characterization of the pond ash with respect to structural and geotechnical applications.

Fig 1.1 Dry disposal

Fig 1.2 Wet disposal

1.2 Pond ash: An overview

There are three types of ash produced by thermal power plants, 1) fly ash 2) bottom ash and 3) pond ash. The very fine particles that are collected from the gases by precipitators are known as Fly ash; whereas, the ash that is collected from the bottom of the boilers is known as Bottom ash. When fly ash and bottom ash are mixed together are transported in the form of slurry and stored in the lagoons, the deposit is called Pond ash. The volume of pond ash produced by thermal power plants is very large compared to that of the other two ashes, fly ash and bottom ash.

Disposal of fly ash in storage ponds and in landfills prevents valuable agricultural land from being used to feed people and thus stimulate the economy. This practice also:

- lowers soil fertility,
- contaminates soil and groundwater,
- interferes with pH balance and the portability of water, and
- Corrodes exposed metal.

1.3 Classification of coal ash as per ASTM:

Based on the chemical composition, ash is classified into two classes, F and C. When the chemical composition does not fall under the requirements of either Class C or F as given in ASTM C 610, the coal ash can classified as off-specification pond ash.

- Class F fly ash is produced from burning anthracite and bituminous coals. This fly ash possess very little or no cementitious property even though it contains silicious and aluminious material or only silicious material. In presence of moisture and at ordinary temperature, the ashes in finely powdered form, form cementitious materials by reacting with calcium hydroxide. (Chu et al. 1993).
- Class C fly ash is normally produced from lignite and subbituminous coals. It contains a significant amount of calcium hydroxide also known as lime (Cockrell et al. 1970). It is also cementitious besides possessing pozzolonic properties. (ASTM C 618-99).

The color of the ashes depicts the chemical composition of the ashes. The calcium oxide content and organic content is estimated by the color of the ash. Lighter color fly ash generally indicates greater percentage calcium oxide. Darker colors suggests higher organic content (Cockrell et al.1970).

Table 1.1: Chemical requirements of Class F and Class C Fly ash.

Chemical requirements	**Class F fly ash**	**Class C fly ash**
Silicon Dioxide (SiO2) + Aluminum Oxide(Al2O3) + Iron Oxide (Fe2O3),min(%)	70	50

Sulfur Trioxide (SO3), max (%)	5	5
Moisture Content, max (%)	3	3
Loss on Ignition, max (%)	6	6

1.4 Environmental impacts of coal ash:

The coal ashes namely fly ash being very light in weight can fly in air causing environmental pollution. It can directly or indirectly cause health hazards. Some of the environmental problems associated with fly ash are:

- The disposal of ashes needs the acquisition of fertile plant thereby causing the ecological imbalance and environmental problems due to the depletion of natural sites
- Ash handling and disposal system causes environmental pollution as a result of emission of plant enroute and dumps.
- The overflow of ash water from the ash ponds into the nearby water bodies results in contamination of the river/sea and agricultural field which are situated nearby.

In the air, fly ash can cause people to suffer from such health hazards as bronchitis, silicosis, asthma, and lung cancer. Under such circumstances, management of fly ash is of utmost importance.

1.5 Strength Characteristics of Fly ash

It is advisable to enhance and improve some properties of pond ash for its effective usage in various geotechnical applications as a dominant construction material. This can be achieved by stabilizing it by addition of some suitable stabilizer like lime and/or suitable admixtures. The present work aims at evaluation of the effectiveness of addition of lime as stabilizing agent and Ground Granulated Blast Furnace Slag as admixture in stabilizing the waste product like pond ash and its suitability to be used as a construction material for structural fills and embankment materials. The various properties such as consistency limits, compaction properties, strength characteristics and settlement criteria are the most critical properties to be evaluated for its utilization in various constructional and geotechnical works. In the present work, an attempt has been made to evaluate the above stated geo-engineering properties of pond ash and pond ash treated with various proportion of lime and slag. The physical and chemical characteristics of the fly ash samples were determined by conducting Specific gravity test, Hydrometric analysis. Pond ash was mixed with 0%, 3%, 6%, 9% and 15% of lime and 0%, 5%, 10%, 15% of slag and UCS and Permeability tests are conducted. Lime and slag are taken as a percentage of dry weight of Pond ash. The UCS samples were cured for 0, 3, 7, 14 and 28 days with constant temperature of 27^0C and permeability samples for 0, 7, 14 and 28 days to evaluate the effect of curing period on strength and hydraulic conductivity of slag activated lime stabilized pond ash.

1.6 Lime: An overview

Lime, chemically known as CaO or $Ca(OH)_2$ is one of the oldest construction material. It is by-product of burned lime stone. The soil lime mixture was oldest practice for construction of roads by the Romans. Due to the lack of proper knowledge on the strength characteristics of lime, it was not massively utilized for construction works up to 1945. Considering the economic aspects and due to the wide spread knowledge on the beneficial properties of lime, the soil and waste materials are stabilized using lime and are used in various constructions namely highways, embankments, slope protection, railways, foundation base, airports, canal lining etc. The enormous usage of lime in the recent times is basically due to the simplicity of its technology and construction and mostly because it is a economical construction material that attracted the engineers which routed to its wide usage. The soil and waste materials when treated with design and construction technique under controlled conditions chemically transforms them into efficient materials. Lime, individually or with combination of any other materials as admixtures can be effectively used as stabilizing agent to treat the waste materials and ranges of soil.

Fine grained soils are basically stabilized using lime as stabilizer. The suitable amount of clay and mineralogy of the soil decides the stabilization of the particular soil with lime for attaining long term strengths. The benefits of lime over soil can be well appreciated when the stabilization is left over longer period, which is known as “curing”. The effect of lime stabilization can be studied over curing till 28 days. When the lime content taken is increased, the unconfined strength of soil lime mixture increases up to optimum point of lime. Above this point, addition of lime would not result in any increase of strength as the additional lime would be left as waste. The strength of lime over soil or waste is observed to depend upon lime content, curing period, compactive energy and water content.

Proper amount of lime added to reactive soil results in attaining maximum strength through the process of stabilization. The long term strength is developed by the prolonged pozzolonic reaction which occurs when lime is added to soil. When pH is maintained high (above 10), the full term pozzolanic reaction may continue for a very prolonged period of time even many years as long as enough lime is present.

1.7 Uses of coal ash

- ✓ In Land Fill
- ✓ Structural fill for reclaiming low lying areas
- ✓ Cement manufacturing
- ✓ Road and embankment construction
- ✓ Agriculture and forestry
- ✓ Brick manufacturing
- ✓ Part replacement of cement in mortar and concrete
- ✓ Dyke raising
- ✓ Stowing materials for mines
- ✓ Hydraulic structures
- ✓ Other medium and high value added products

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Massive urbanization in the recent times has led a high increase in the power demands. To cater to the increasing demands of power, electricity generation has to be done on a large scale. The coal reserves of India are approximately 200 billion metric tons. Due to the huge availability, around 90% of the thermal power stations in India are coal based. The total installed capacity of electricity generation is 100,000 MW in India. Of which, 73% of it is from thermal power generation. In our country, overall 85 coal based thermal and other power stations are present. A high calorific value of about 3,000–4,000 kcal/kg is observed in the coal of our country. The coal in India contains high ash content (30-50%) which resulted in high ash production generated as waste material. India produces about 180 million metric tons of fly ash annually. Due to the high coal ash produced, its safe disposal has become a very serious problem. Of the various methods of disposal of coal ashes produced in thermal power plants available, wet method is most commonly used in India. For this method, large acres of land and water bodies are polluted which results in health hazards and environmental pollution. To decrease the disposal and adverse effects of coal ashes, proper utilization has to be done on a large scale. The nation uses only about 38 percent of its total fly ash production for cement manufacturing (approximately10.42 million metric tons), land filling, brick manufacturing, mine filling, agriculture and other uses. With the continued reliance on coal, India will have huge supplies of fly ash in the years to come which is estimated to be about 225 million metric tons of fly ash, to be stored in more than 1.8 million acres of ponds by 2032. In 1994, the utilization of the coal ashes in various industries under various purposes was just mere 3%. But the utilization of coal ashes has gradually been increasing in India due to the realization about the need for conservation of the environment. Government of India had commissioned a Fly Ash Mission (FAM) in 1994 for bringing awareness and to build confidence among the producers and the consumer agencies on the safe disposal and utilization of fly ash, through technology demonstrated projects. Ministry of Environment and Forests of the Government of India (MOEF 1999) issued a notification issued on September 14, 1999, which established the basis for increasing the utilization of fly ash and environment conservation efforts to be set up in the country. A huge increase in utilization of ashes over the years, to a total of 20% utilization of fly ash, within a span of 3 years and 100% utilization within 15 years was demanded in this notification. A project search conducted in 1984, Electric Power Research Institute's (EPRI) manual (Glogowski et al. 1992) stated that Fly ash was used as constructive material in construction of 33 embankments and 31 areas fills in North America. About 33% of the fly ash and bottom ash produced in the United States were extensively used in different civil applications as stated by The American Coal Ash Association (ACAA 1999). The utilization of coal ashes next to its use in cement, concrete, and grout (16.1%) in structural fills was its second major application (5.1%). Based on a survey conducted on nine thermal power stations, the use of fly ash in Japan was about 41% in Landfills construction. The guidelines for the utilization of fly ash in road embankments were published by Indian Road Congress (IRC 2001). Due to the free lime available in fly ash, self-hardening is observed in fly ash which makes it suitable attractive construction material for various applications. The properties of the coal ashes produced are varied depending on the nature of coal, fineness of pulverization, type of furnace used and firing temperature.

2.2 Literatures on Pond Ash and Its Geo-Engineering Properties

The suitability of pond ash as a construction material in various fields of Civil Engineering was studied by different researchers and many research works have been done in this area. Some of the works are summarized below.

Gray and Lin (1972) studied the variation of specific gravity of the coal ash and they showed that the variation in specific gravity depends on combination of many factors such as gradation, particle shape and chemical composition.

McLaren and Digioia (1987) indicated that the low dry densities from ash fills are due to low specific gravity of ashes as compared to soils. Due to this, the pressure exerted on the foundation structure will be less which makes it wide usage in embankments on weak foundation soils, backfill material for retaining walls, and reclamation of low-lying areas.

Rajasekhar (1995) reported that coal ash mainly consists of glassy cenospheres and some solid spheres. The chemical composition particularly the iron content of coal ashes are varied mainly due to the presence of large number of hollow ceno-spheres also resulting in low specific gravity of coal ash which results in difficulty in removal of entrapped air.

Pandian and Balasubramanian (1999) determined the co-efficient of permeability of ash which inturn depended upon the grain size ,degree of compaction and pozzolanic activity The bottom and pond ashes have a higher value for permeability coefficient as they are coarse grained and devoid of fines compared to fly ash. The consolidation pressure has negligible effect on the permeability.

Ahmaruzzaman. M., (2009) discussed the utilization of fly ash in construction, as a low-cost adsorbent for the removal of organic compounds, flue gas and metals, light weight aggregate, mine back fill, road sub-base, and zeolite synthesis. It was found that fly ash is a promising adsorbent for the removal of various pollutants and has good potential for use in the construction industry. The investigations conducted revealed that the unburned carbon component in fly ash plays an important role in its adsorption capacity.

Bera and Ashis kumar (2010) studied the effect of pond ash on the engineering properties of fine grained soils. It was found that the liquid limit of the soil pond ash mixture decreases gradually with increase in percentage of pond ash adopted in the range of 0 to 55 % in the fine grained soil. Up to the range of 20% the plasticity index of soil pond ash mixture decreases. The engineering properties such as maximum dry density, optimum moisture content, unconfined compression strength and California bearing ratio also changes significantly with addition of pond ash content in the fine grained soil.

Bharathi Ganesh et.al (2012) characterized the engineering properties of Pond ash for its use as fine aggregate in concrete. The different properties such as Specific gravity, fineness, gradation, texture, physical and chemical of Pond ash are evaluated and are compared with natural river sand. The results showed that Pond ash can be effectively used as fine aggregate.

Prasenjit Ghosh and Sudha Goel (2014) determined the environmental impacts of open dumping of pond ash around a thermal power plant by conducting physico chemical characterization of three pond ash samples collected. Physical characterization of the samples included determination of Total Solids, Volatile Solids, Fixed Solids, specific gravity, specific surface area, hydraulic conductivity, dry densities, particle size distribution and performing Scanning Electron Microscopy for obtaining morphological characteristics. The different chemical characteristics of the samples were analyzed using Surface reactivity and EDS. Specific surface area gave fineness data and EDS gave elemental composition of the ash samples. The results were used to assess the potential hazards of the samples.

Singh and Sharan (2014) showed the effect of compaction energy and degree of saturation on strength characteristics of compacted pond ash. The pond ash sample collected from ash pond of Rourkela Steel Plant (RSP) is subjected to compactive energies varying from 357 kJ/m3 to 3488 kJ/m3 and optimum moisture content and maximum dry densities are found out by conventional compaction tests corresponding to different compactive energies. The compaction characteristics of the specimen at different dry densities and moisture contents are determined. The reports indicated that the dry density and the strength determined can be modified suitably for these samples can be controlled by controlling the compactive energy and moulding moisture content. The study concluded that the strength attained by the pond ash by the tests was as good as similar graded conventional earth materials which can be used to replace the natural earth materials in geotechnical constructions.

2.3 Literature on lime Stabilized Pond ash

Ambarish Ghosh (2010) studied the suitability of stabilized pond ash for road base and sub base construction by conducting laboratory tests on Class F pond ash alone and stabilizing with varying percentages of lime (4, 6, and 10%) and Phospho Gypsum (PG) (0.5, and 1.0). The influences of lime content, PG content, and curing period on the bearing ratio of stabilized pond ash were discussed in this paper. The empirical model has been developed to estimate the bearing ratio for the stabilized mixes through multiple regression analysis. A linear empirical relationship has been presented to estimate soaked bearing ratio from unsoaked bearing ratio of stabilized pond ash. The results indicated that pond ash-lime-PG mixes have potential for applications as road base and sub base materials.

Chand S. K. and Subbarao. C., (2007) studied the effects of lime stabilization on the strength and durability aspects of a class F pond ash. Lime contents of 10 and 14% were used, and the samples were cured at ambient temperature of around 30°C for curing periods of 28, 45, 90, and 180 days. The samples were subjected to unconfined compression tests, point load strength tests, rebound hammer tests, and slake durability tests. Unconfined compressive strength UCS values of 4.8 and 5.8 MPa and slake durability indices of 98 and 99% were achieved after 180 days of curing for samples stabilized with 10 and 14% lime, respectively. Good correlations have been derived for strength parameters obtained from these tests and also between UCS and slake durability index.

Sreedhar. M.V.S. and Manoj. K., (2011) studied effect of lime on compaction and CBR characteristics of pond ash by taking various substitution levels of 2%, 5%, 10% and 20% including the role of curing period. For the materials used in this research when pond ash was substituted by 20% of Lime and cured for 28 days, the CBR value was found to be 156%. This study brings out the promising performance of Lime stabilized Pond Ash as an overlay.

2.4 Literature on Stabilization of Pond ash with slag

Admixtures in lime stabilized pond ash are the ingredients other than pond ash, lime and water that are added to the mix immediately before or during mixing to modify one or more of the specific properties of pond ash. The admixture is generally added in a relatively small quantity. A degree of control must be exercised to ensure proper quantity of admixture.

The admixture used in this stabilization is Ground Granulated Blast Furnace Slag.

Slag is a by- product of the iron-making process. When it is quenched with water and rapidly chilled, it forms a glassy granulated material of sand-like consistency. Because of its high calcium silicate content, it has excellent cementitious properties. When finely ground and combined with a suitable activator, slag sets in a manner similar to Portland cement.

Hogan, F. J. and Meusel, J. W., (1981) studied the evaluation of a ground granulated blast furnace slag as a partial replacement for Portland cement in mortars and concrete. The ground slag was evaluated for strength-producing properties as well as durability performance by replacing 40 to 65% Portland cement with it. This study showed that the ground slag when used to replace 40 to 65% Portland cement significantly improved strengths, sulfate resistance, and alkali aggregate reactivity.

Laxmikant Yadu et.al (2013) evaluated the potential of granulated blast furnace slag (GBS) with fly ash to stabilize a soft soil using compaction and California bearing ratio (CBR) test with different amounts of GBS, i.e. 3, 6, and 9% with different amount of fly ash i.e. 3%, 6%, 9% and 12%.

2.5 Scope and Objective of the Present Work

With the tremendous increase in usage of coal in thermal power plants and the production of coal ashes, the need for the usage of coal ashes in geotechnical applications has evolved. Thus evolved the process of stabilizing pond ash with other agents and improving its properties. In view of this it is proposed to scientifically study the following aspects in the present study.

- Determination of optimum quantities of different raw materials used namely Pond ash, lime and the Slag.
- Study the effect of curing period on the strength and hydraulic conductivity of lime stabilized pond ash using slag.
- Study the effect of lime as stabilizing agent by adopting different proportions on the strength and hydraulic conductivity of pond ash.
- Study the effect of the slag on various properties of lime stabilized pond ash.

CHAPTER-3

EXPERIMENTAL PROCEDURE

3.1 Introduction

Safe disposal of the ash without adversely affecting the environment and the large storage area required are major concerns of a thermal power plant. In this concern, utilization of coal ash is given more importance these days rather than dumping it causing various health hazards and environmental pollution. The coal ash thus produced from thermal plants is in huge quantities and so its massive use has to be adopted to reduce the disposal problems. Hence it is decided to be utilized in various geotechnical and structural engineering applications as in embankments construction, as sub-base material, as backfill material etc. To transform the coal ashes produced as a waste material to a construction material, it has to be stabilized with effective stabilizers and admixtures. The behavior of ashes has to be studied at various conditions and to enhance the required properties to use effectively in field. A detailed study and understanding of chemical and physical properties of the ashes is essential for the effective utilization of coal ashes. The trends and the behavior pattern of various properties observed through the experimental study can be used to predict the behavior of field structures. The behavior of the structures in the field can be assessed by the various tests and mathematical relationship can be formulated. In the present study the influence of curing period on the strength and hydraulic properties of lime stabilized pond ash with slag as admixture was determined by light compaction tests, unconfined compressive strength test, and constant head permeability tests. The details of the different materials used, sample preparation involved and experimental procedures adopted are elaborated in the present chapter.

3.2 Experimental Procedure

3.2.1 Materials Used

3.2.1.1 Pond ash

The pond ash used in the present study was collected from NTPC, Angul. It is sieved to remove the lumps, foreign and vegetative matter. The samples thus collected are thoroughly mixed to attain homogeneity and is oven dried at a temperature of around 110^0 C for 24 hours. The Pond ash samples are stored in air tight containers for further experimental use.

3.2.1.2 Lime

The lime, which is used as an agent of stabilization, is bought from local market. The lime has a purity of 95.2%. The samples are powdered and sieved through 15 microns sieve and stored in air tight container for subsequent use.

3.2.1.3 Ground Granulated Blast Furnace Slag (GGBS)

The admixture used in this study is ground granulated blast furnace slag. The GGBS sample was collected from slag granulation plant of Rourkela steel plant. The same was mixed thoroughly to get homogeneity in the same and was powdered in a ball mill. The Baline fineness value of the ground slag was 410 m^2/kg.

Fig 3.1 Pond ash

Fig 3.2 Lime

Fig 3.3 Ground Granulated Blast Furnace Slag

3.2.2 Physical properties of Pond ash

The physical properties of the pond ash samples which are oven dried are determined and tabulated in table 1.

Table 3.1: Engineering properties of Pond Ash

Parameter	Value
Specific gravity	2.04
Consistency	Non plastic
Coefficient of uniformity, Cu	4.65
Coefficient of curvature, Cc	0.84

Standard proctor test results	
Maximum dry density (g/cc)	1.185
Optimum water content (%)	27

3.3 Determination of Index Properties

3.3.1 Determination of Specific Gravity

The specific gravity of pond ash was determined according to IS: 2720 (Part-III, section-1) 1980 taking kerosene as the solvent. The specific gravity thus determined was found to be 2.04 for pond ash.

3.3.2 Determination of Grain Size distribution

Pond ash passing through 75μ sieve was used for determining grain size analysis. Particle size distribution of the coarse particles of pond ash was done by sieve analysis according to IS: 2720 part IV and finer particles according to IS: 2720 part IV by using hydrometric analysis. It remarkably showed 52% of particles passing through 75μ sieve. Hence the pond ash particles size varies from fine sand to silt size. The Coefficient of uniformity (Cu) and coefficient of curvature (Cc) thus determined from the grain size distribution was found to be 4.65 and 0.84 respectively indicating uniform graded samples.

3.4 Determination of Engineering Properties

3.4.1 Moisture Content Dry Density Relationship

The specimens are prepared with lime percentages 0, 3, 6, 9 and 15% and slag percentages 0, 5, 10, 15% in the mould of volume 1000 cc in 3 layers with 25 blows each with the standard rammer. Thus a total of 20 specimens are obtained for slag. The specimens kept in oven for 24 hours give the moisture content. Thus the maximum dry densities and the corresponding water contents for the different proportions of lime and slag in pond ash are determined from the graphs between dry density and the corresponding water content and are given in table 2. The results thus obtained are used as basis for the unconfined compressive tests and the permeability tests.

Table 3.2: Maximum dry density of samples at various percentages of pond ash, lime and slag

Slag (%)	Lime (%)				
	0	3	6	9	15
0	1.185	1.22	1.243	1.2612	1.296
5	1.225	1.256	1.272	1.299	1.332
10	1.264	1.29	1.3137	1.3216	1.348
15	1.283	1.31	1.325	1.341	1.363

Table 3.3: Optimum Moisture Content of samples for different percentages of pond ash, lime and blast furnace slag.

Slag (%)	Lime (%)				
	0	3	6	9	15
0	27	24	23	22	21
5	24	22	21	20	19
10	23	21	20	19	18
15	23	21	20	19	18

3.4.2 Unconfined Compressive Strength tests:

The specimens of 5cm*10 cm prepared with 0, 3, 6, 9 and 15 % of lime and 0, 5, 10, 15% slag in the unconfined compression moulds are used in this study. Curing periods of 0, 3, 7, 14, and 28 days are adopted at a standard temperature of 27^0. The average of 2 samples is reported as the final strength which accounts to 200 samples for slag. The samples are prepared with the maximum dry density and the optimum moisture content values resulted from the light compaction test. They are compacted using the hydraulic jack. The specimens are placed in the unconfined compression apparatus with a proving ring of maximum load 1 KN. The load is applied and the proving ring readings are noted down for every 0.5 mm penetration on dial gauge. The loading and recording are continued till the point where the reading on proving ring starts decreasing. A graph is plotted between the load and deflection, i.e. stress strain curve is obtained which gives the unconfined strength of the specimen for the particular proportion of lime and slag in pond ash.

Fig 3.4 **UCS samples sealed with wax coating and cured at temperature of 27^{0}C**

Fig 3.5 Stabilized sample mounted in the compression testing machine.

Fig 3.6 Failure pattern in the stabilized specimens

Table 3.4(a): Unconfined Compressive Strength of samples (kPa) at curing period of 0 days

Slag (%)	Lime (%)				
	0	3	6	9	15
0	38.2	76.8	111.06	125.5	186.6
5	52.22	80.4	119.2	131.3	200.3
10	64.37	85.7	124.7	137.23	207.62
15	59.05	106.55	143.83	175.55	359.55

Table 3.4(b): Unconfined Compressive Strength of samples (kPa) at curing period of 3 days

Slag (%)	Lime (%)				
	0	3	6	9	15
0	55.5	113.75	139.5	234.65	262.5

5	78.95	169.31	187.86	288.41	398.7
10	125.66	225.48	349.5	643.58	985.63
15	92.29	539.15	795.3	1053.53	1921.79

Table 3.4(c): Unconfined Compressive Strength of samples (kPa) at curing period of 7 days

Slag (%)	Lime (%)				
	0	3	6	9	15
0	78.41	135.72	154.47	326.92	609.03
5	202.8	343.33	456.47	728.29	1098.57
10	287.34	504.21	670.25	1050.29	1807.13
15	167.49	991.55	1130.6	1658.9	2922.18

Table 3.4(d): Unconfined Compressive Strength of samples (kPa) at curing period of 14 days

Slag (%)	Lime (%)				
	0	3	6	9	15
0	126.85	149.1	209.65	392.82	1859.23
5	239.55	507.06	647.83	1407.93	2183.25
10	303.69	796.2	1056.7	2099	2929.17
15	243.82	1299.2	1625.97	2508.1	4218.55

Table 3.4(e): Unconfined Compressive Strength of samples (kPa) at curing period of 28 days

Slag (%)	Lime (%)				
	0	3	6	9	15
0	163	240.48	344.74	1337.16	1084.37
5	632.9	714.68	1280.91	2226.07	1624.47
10	899	1029.46	2081.71	2927.49	2273.29
15	688.8	1531.36	3225.41	3875.37	3466.55

3.4.3 Permeability tests:

The samples are prepared in the permeameter mould by replacing pond ash with lime at 0, 3, 6, 9 and 15 % and slag in 0, 5, 10, and 15%. The samples in the moulds are saturated and cured for 0, 7, 14 and 28 days. A total of 20 permeability tests have to be conducted for slag. The samples are connected to water supply system and ensured that the air bubbles are removed. After attaining steady flow condition, sufficient quantity of water is collected and the time interval is noted down. The total head loss and the length of specimen are noted. Thus the hydraulic conductivity for the samples with different proportions of lime and slag in pond ash are calculated and reported.

Fig 3.7 Constant head Permeameter

Fig 3.8 Curing of specimens before permeability test

Fig 3.9 Constant head permeability test

Table 3.5 (a): Co-efficient of permeability, k (in 10^{-5} cm/sec) of pond ash stabilized with different percentages of lime and blast furnace slag after 0 days curing period

Slag (%)	Lime (%)				
	0	3	6	9	15
0	10.1	9.83	9.59	9.21	8.89
5	9.68	9.46	9.23	8.93	8.67
10	9.44	9.23	9.005	8.71	8.46
15	9.21	9.07	8.84	8.49	8.19

Table 3.5 (b): Co-efficient of permeability, k (in 10^{-5} cm/sec) of pond ash stabilized with different percentages of lime and blast furnace slag after 7 days curing period

Slag (%)	Lime (%)				
	0	3	6	9	15
0	9.81	9.429	9.207	8.946	8.446
5	9.42	9.17	8.916	8.663	8.092
10	9.195	8.967	8.634	8.287	7.786
15	8.887	8.541	8.251	7.814	7.21

Table 3.5 (c): Co-efficient of permeability, k (in 10^{-5} cm/sec) of pond ash stabilized with different percentages of lime and blast furnace slag after 14 days curing period

Slag (%)	Lime (%)				
	0	3	6	9	15
0	9.43	8.915	8.73	8.526	7.917
5	9.17	8.724	8.525	8.236	7.458
10	8.818	8.417	8.128	7.682	7.019
15	8.434	7.969	7.592	7.234	6.489

Table 3.5 (d): Co-efficient of permeability, k (in 10^{-5} cm/sec) of pond ash stabilized with different percentages of lime and blast furnace slag after 28 days curing period

Slag (%)	Lime (%)				
	0	3	6	9	15
0	8.29	7.77	7.622	7.213	6.672
5	8.089	7.578	7.381	7.003	6.379
10	7.699	7.121	6.801	6.384	5.613
15	7.192	6.511	6.118	5.701	4.712

CHAPTER-4

RESULTS AND DISCUSSIONS

4.1 General

Pond ash produced as waste material from thermal power plants is generated in huge amounts. For its effective usage in constructional and geotechnical use, the characterization of pond ash namely the chemical and physical characteristics is essential. Hence the properties such as strength and hydraulic properties are evaluated by conducting laboratory experiments unconfined compressive strength and constant permeability respectively. The results and are reported in this chapter.

4.2 Index properties

4.2.1 Specific Gravity

The specific gravity of pond ash samples collected from NTPC, Angul was determined to be 2.04 by Lechatlier apparatus taking kerosene as solvent. This property is very important for its usage in any geotechnical or structural applications. The specific gravity of ashes is found to be around 2.0, generally (1.6-3.1). The specific gravity of collected samples is less than earthen material. The factors such as gradation, chemical composition and particle shape vary the specific gravity of the ashes. The presence of hollow cenospheres which entrappes the air bubbles, chemical composition of pond ash especially the iron content are the various other factors on which the specific gravity of ashes depend upon.

4.2.2 Grain Size distribution

The grain size distribution of the pond ash samples collected is evaluated and is represented in the fig. 4.1. The results indicated that the size of the particles vary from fine sand to silt size. It remarkably showed that 52% of particles passed 75µ sieve. The Coefficient of uniformity (Cu) and coefficient of curvature (Cc) thus determined from the grain size distribution was found to be 4.65 and 0.84 respectively which indicating uniform graded samples. The degree of pulverization of the coal, the firing temperature adopted, and the presence of foreign matter in coal ashes effects the grain size distribution.

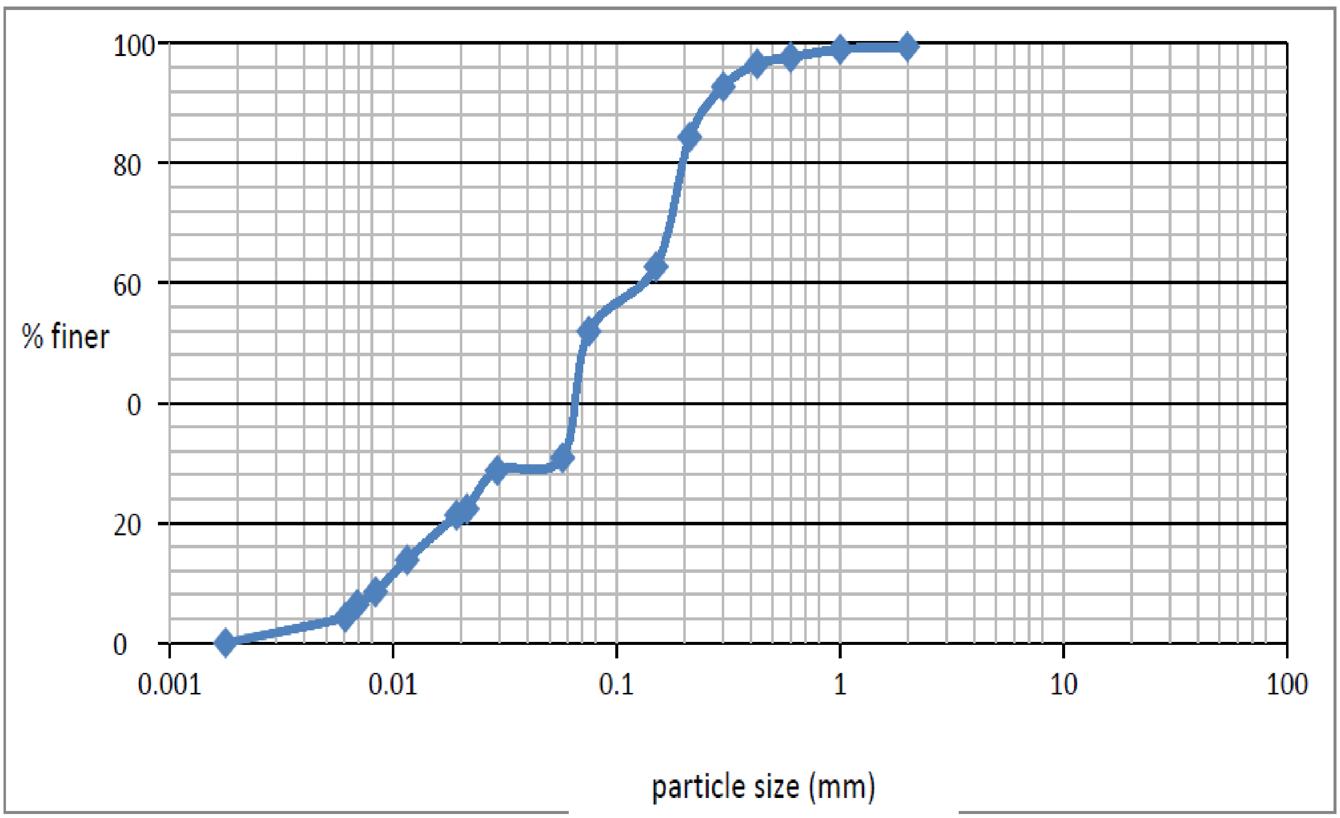

Fig 4.1 Grain Size distribution of pond ash sample

4.3 Engineering properties

4.3.1 Compaction characteristics

The compaction characteristics of the pond ash treated with lime as stabilizer and slag as admixture are studied. The Maximum dry density (MDD) and Optimum moisture content (OMC) of the pond ash samples at various percentages of lime have been evaluated are given in the fig 4.2 and 4.3 respectively. Similarly the MDD and OMC of the samples at various percentages of slag are given in fig 4.4 and 4.5 respectively. From these figures it is found that with an increase in lime content in pond ash, the maximum dry density increased and optimum moisture content decreased. The MDD of pond ash varies from 1.185g/cc to 1.296g/cc and the water content decreased from 27% to 21% for increase of lime content from 0 to 15%.

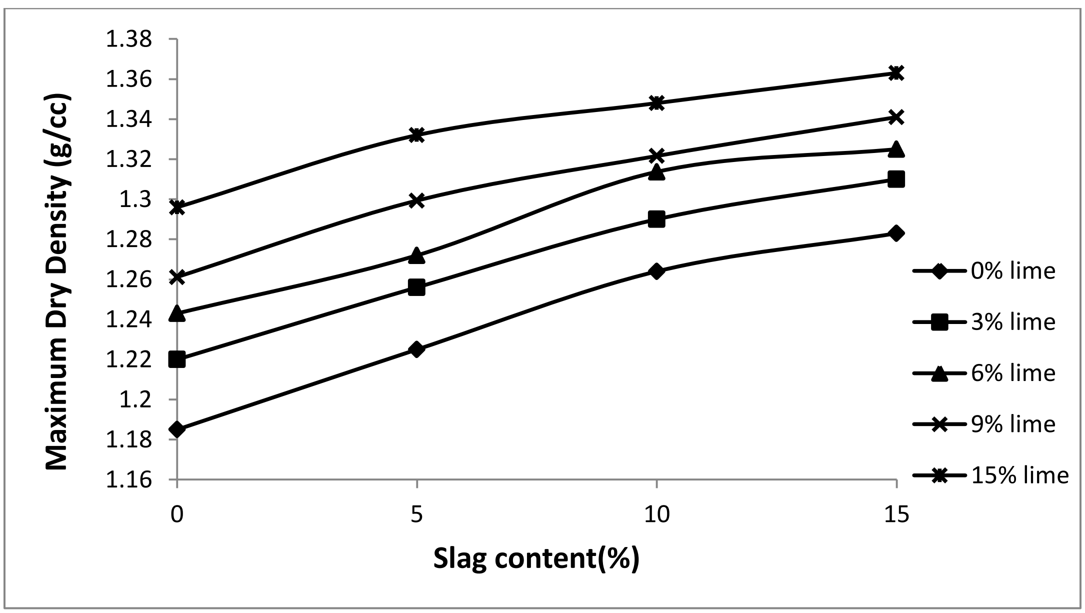

Fig 4.2 Variation of Maximum Dry Density with lime at different percentages of slag.

The pore spaces of pond ash are filled with lime and slag which results in increase of dry density. The trend of variation of MDD and OMC is observed to be reverse pattern as seen in clay. The clay particles which are negatively charged attract the water molecules which results in increase in water content. Due to the flocculated shape and end to end connection, the dry density decreases in clay particles. The structure of slag is different from that of clay. Due to the colloidal reaction of lime, the pore spaces of slag particles are filled with lime instead of water molecules. Hence the void spaces decreases. This results in increase in maximum dry density and a decrease in optimum moisture content.

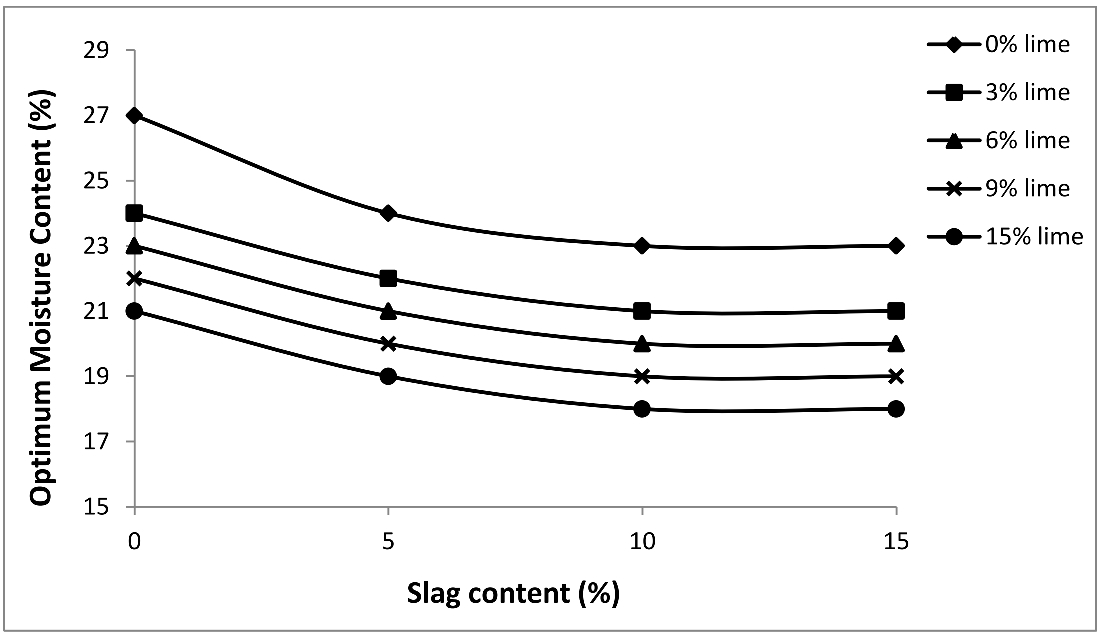

Fig 4.3 Variation of Optimum Moisture Content with slag at different percentages of lime.

With an increase in slag content from 0 to 15% in pond ash, the MDD was observed to increase from 1.185 g/cc to 1.283 g/cc and water content decreased from 27% to 23%. In the present work, different percentages of lime and pond ash are combined and used for effective results.

The MDD of only pond ash was found to be 1.185 g/cc which increased to 1.363 g/cc at 15% of lime and slag in pond ash.

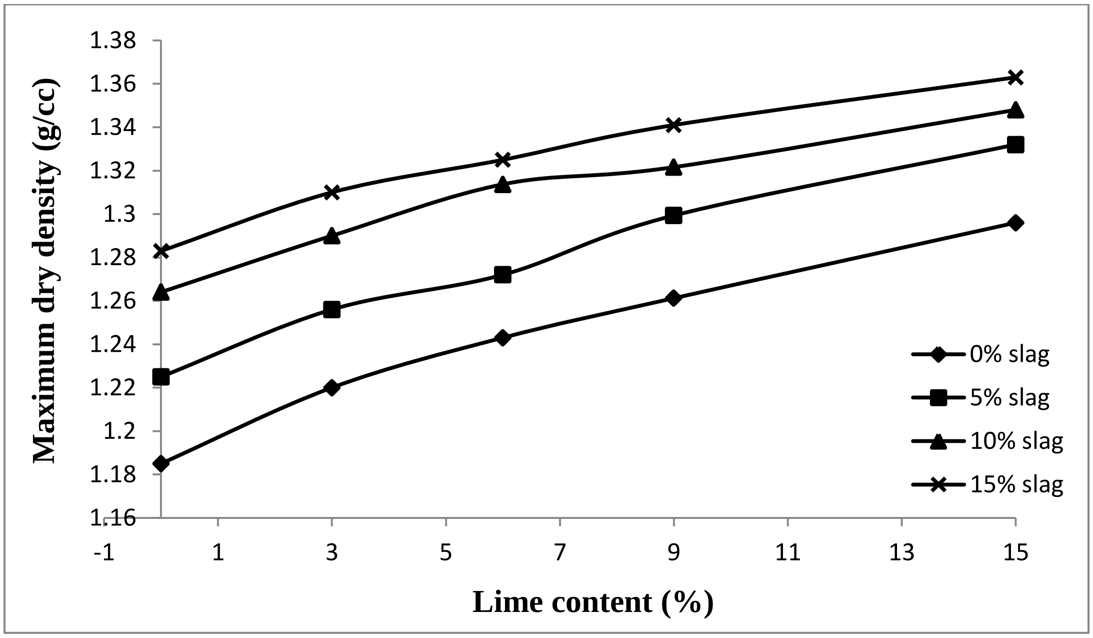

Fig 4.4 Variation of Maximum Dry Density with lime at different percentages of slag.

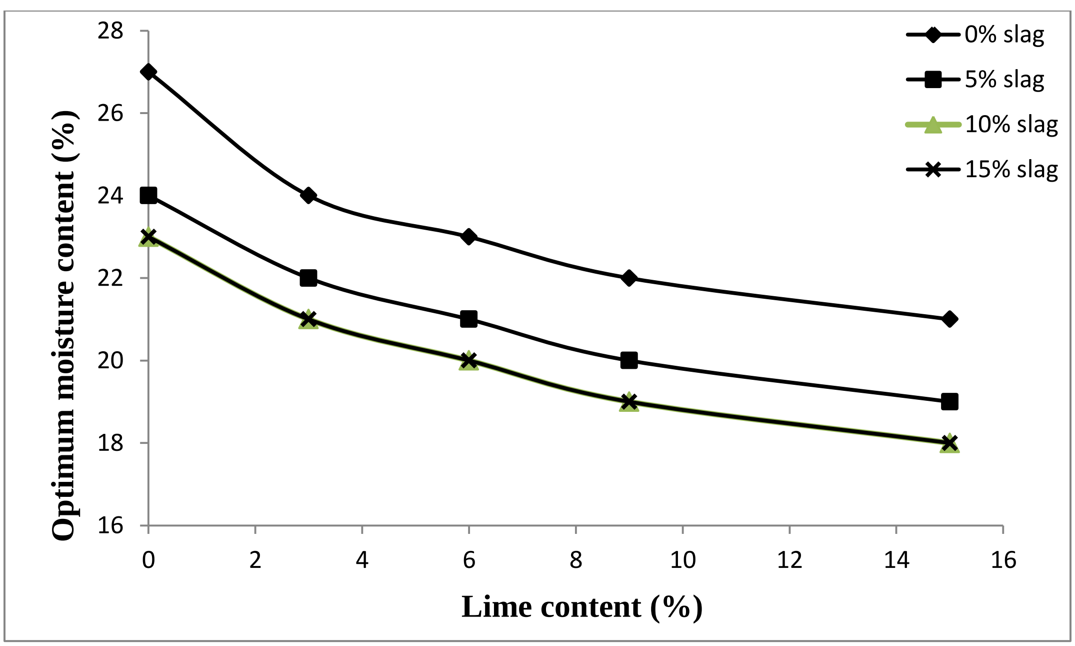

Fig 4.5 Variation of optimum moisture content with lime at different percentages of slag.

4.3.2 Determination of Unconfined Compressive Strength

The Unconfined Compressive strength of pond ash with different percentages of lime as stabilizer (0, 3, 6, 9 and 15) and slag as admixture (0, 5, 10 and 15) is studied. The samples are cured at constant temperature of 27^0C for 0, 3, 7, 14 and 28 days. The deviation of strength at different percentages of lime are evaluated and are given in fig 4.6 (i), (ii), (iii), (iv), (v) for immediate, 3 days, 7days, 14 and 28 days curing respectively. The strength of the pond ash samples increased from 38.2 kPa to 186.6 kPa with no lime to 15% lime respectively.

The slag, taken as admixture now in this present study produces silica. The lime added as stabilizer undergoes pozzolonic reaction with the amorphous silica present in slag. The slag sieved through 75μ sieve is used, which is in finer form resulting in speed reaction. This ultimately results in increase in strength of the pond ash samples when lime and slag are added to it.

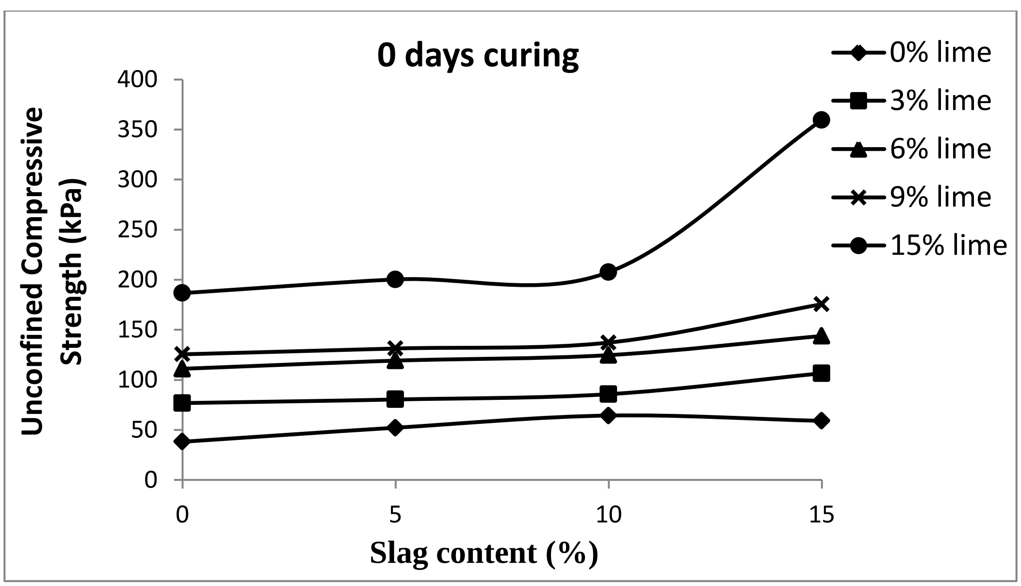

Fig 4.6 (i): Variation in UCS of samples with slag content at 0 days curing

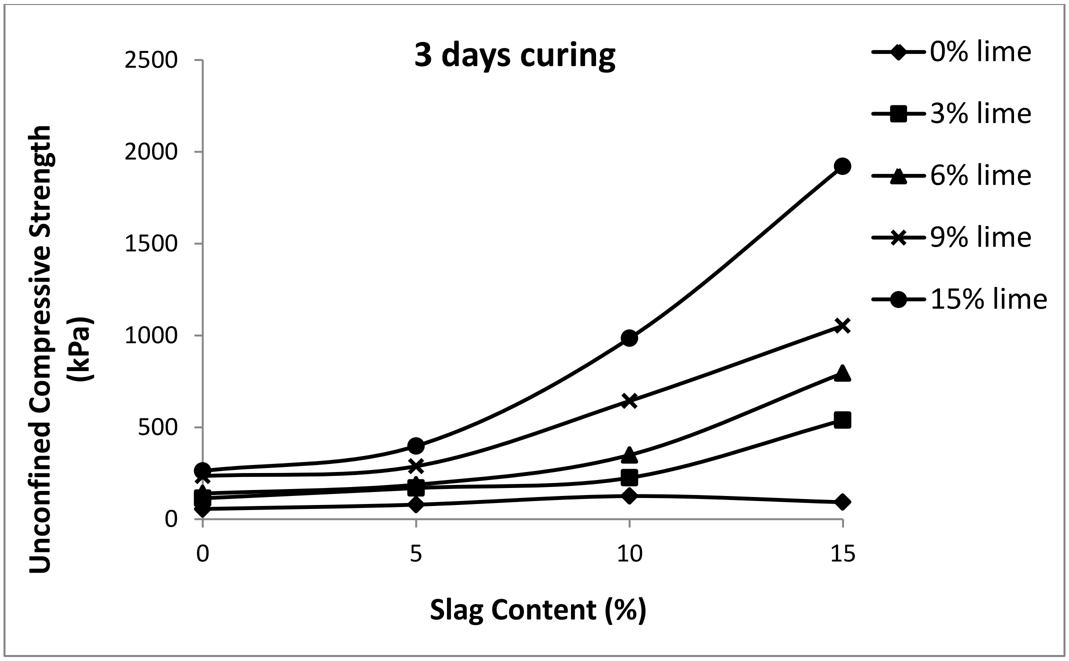

Fig 4.6 (ii): Variation in UCS of samples with slag content at 3 days curing

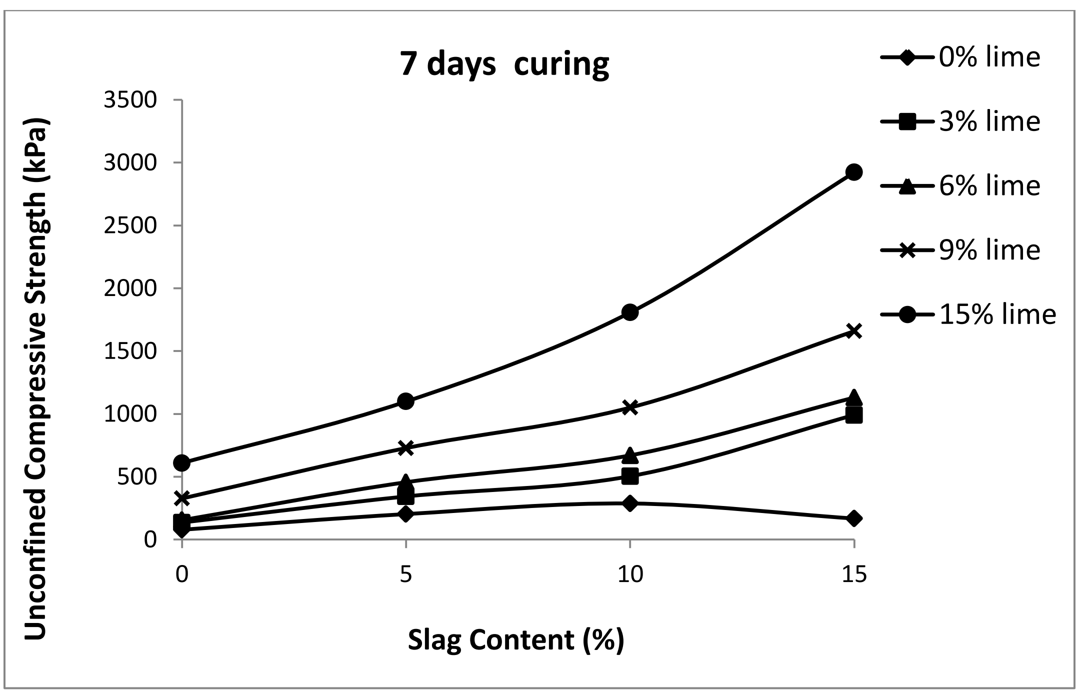

Fig 4.6 (iii): Variation in UCS of samples with slag content at 7 days curing

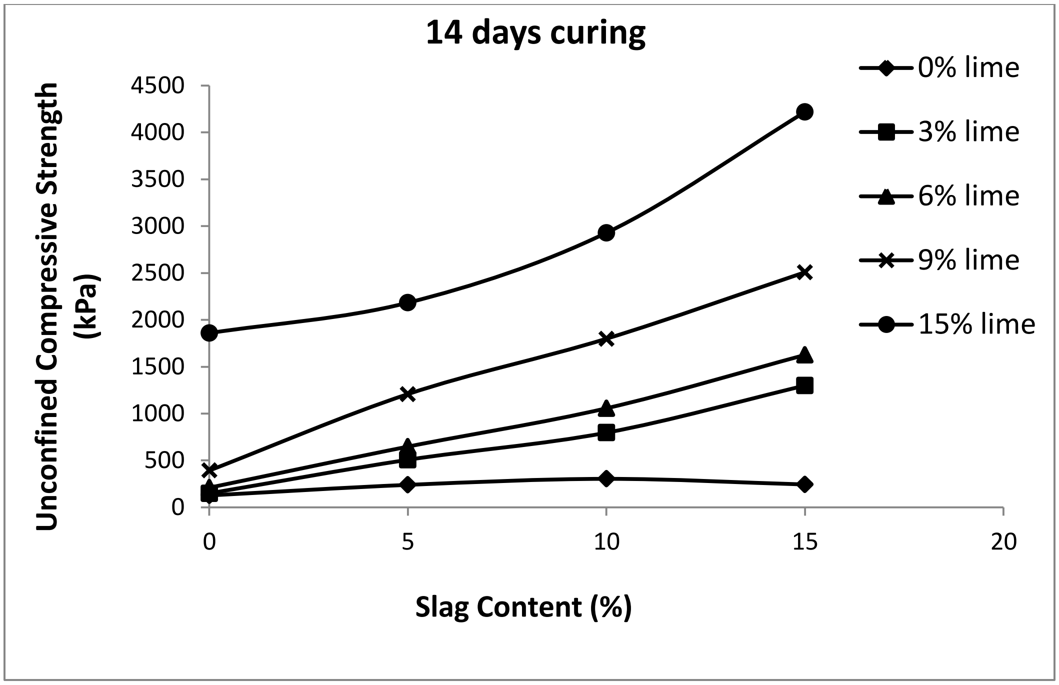

Fig 4.6 (iv): Variation in UCS of samples with slag content at 0 days curing

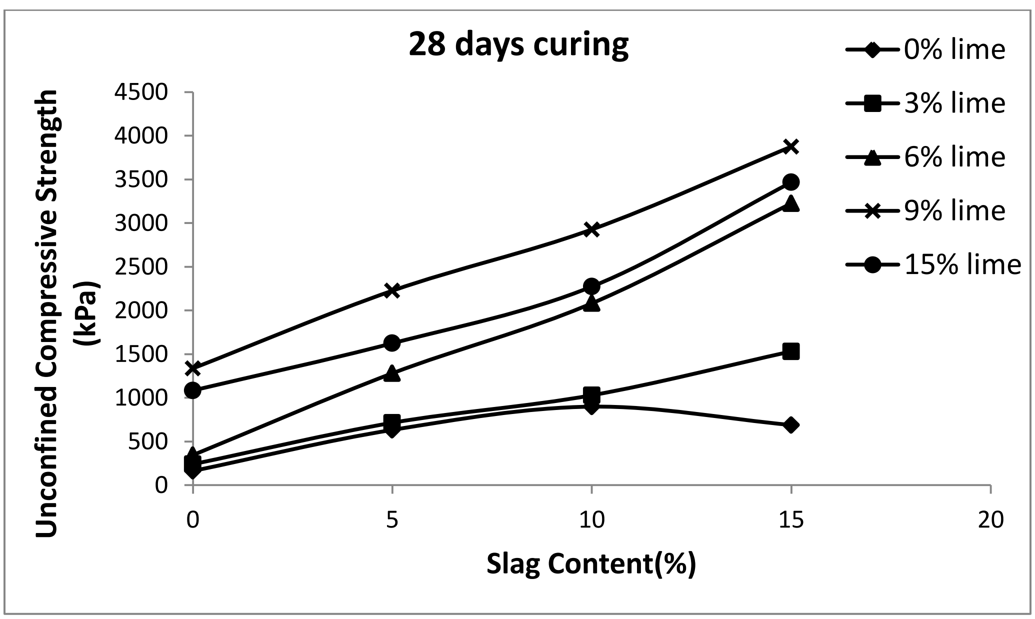

Fig 4.6 (v): Variation in UCS of samples with slag content at 28 days curing

The curing period is observed to have remarkable effect on the strength properties of pond ash treated with lime and slag. With the curing period adopted is increased, the strength of the pond ash samples also increased. The strength of the pond ash increases from 38.2 kPa attained immediately to 163 kPa for 28 days curing. The influence of curing period for different percentages of lime and slag on pond ash is evaluated and is shown in fig 4.7 (i), (ii), (iii), (iv), (v) at 0, 3, 7days, 14 and 28 days curing respectively.

After 14 days curing, there is no significant increment in strength for pond ash combined with 15% lime at different percentages of slag. The Magnesium Oxide (MgO) present in lime is responsible for slow reaction due to hydration. When the lime content is increased to 15%, micro cracks are developed due to slow phase hydration which results in decrease in strength beyond 14 days of curing.

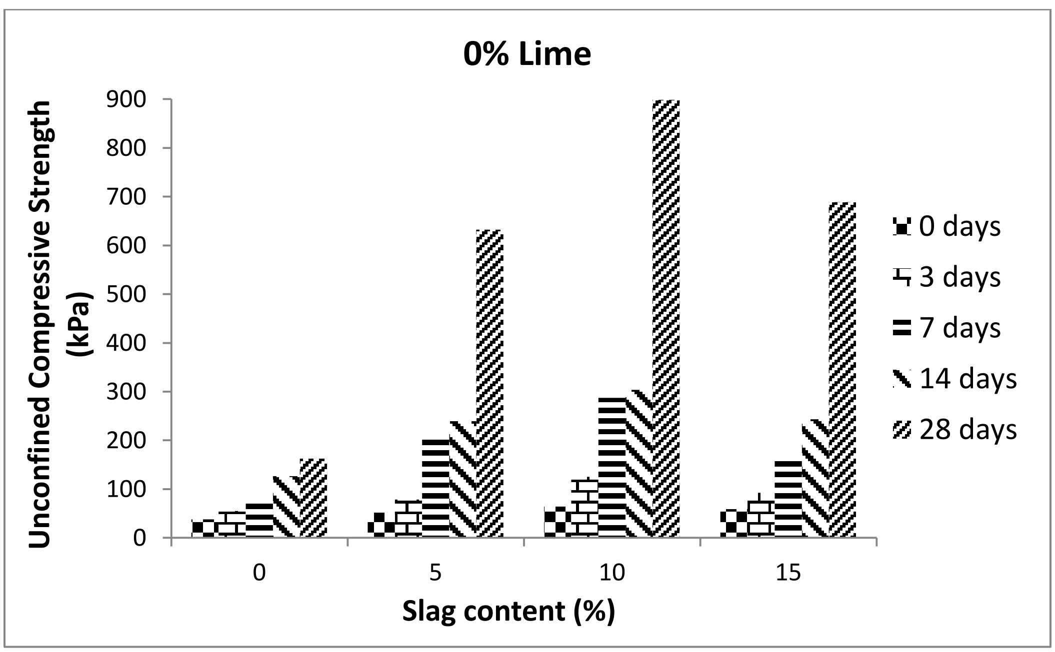

Fig 4.7 (i): Variation in UCS of samples with slag content at 0% lime content

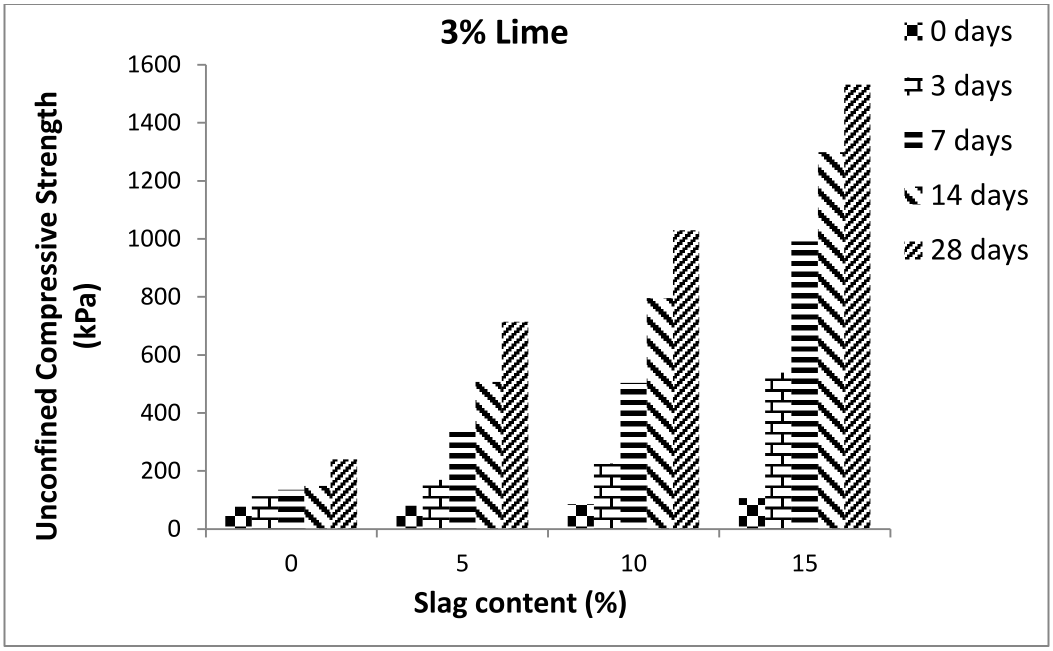

Fig 4.7 (ii): Variation in UCS of samples with slag content at 3% lime content

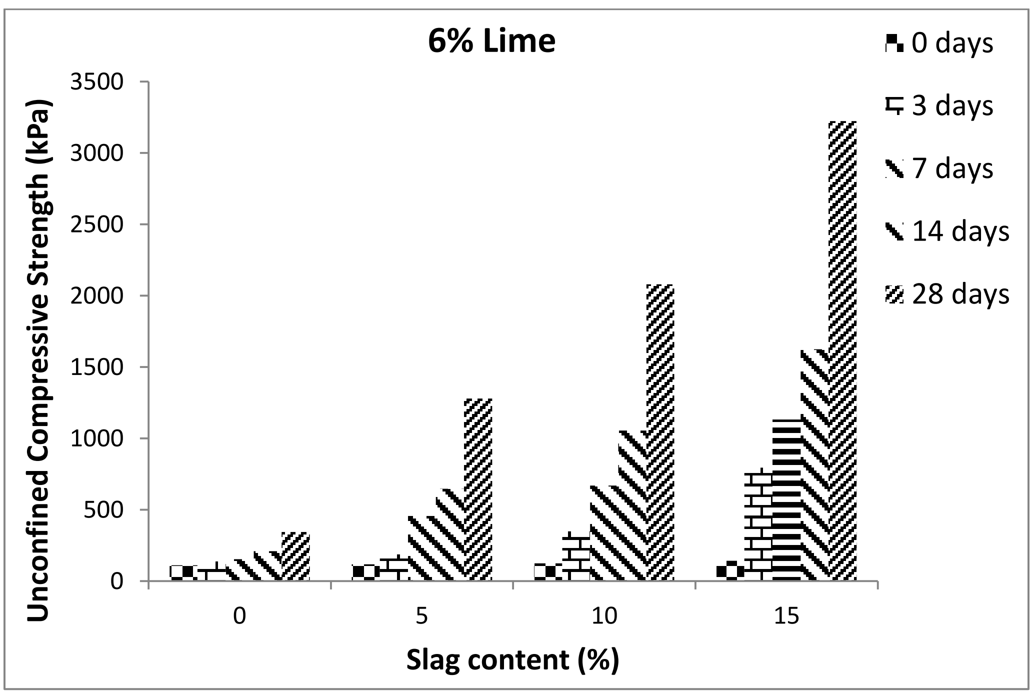

Fig 4.7 (iii): Variation in UCS of samples with slag content at 6% lime content

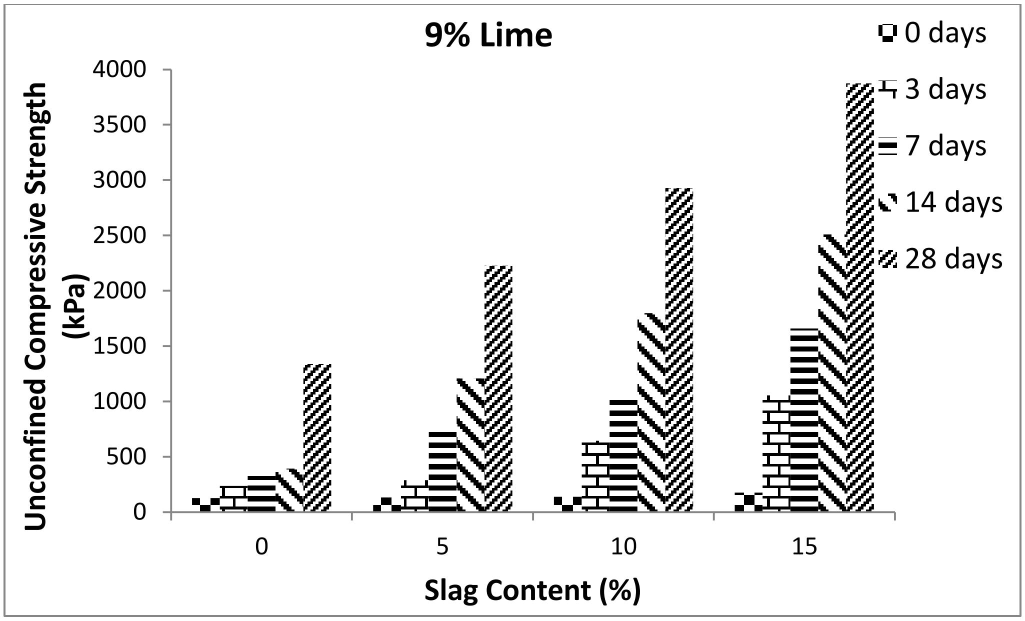

Fig 4.7 (iv): Variation in UCS of samples with slag content at 9% lime content

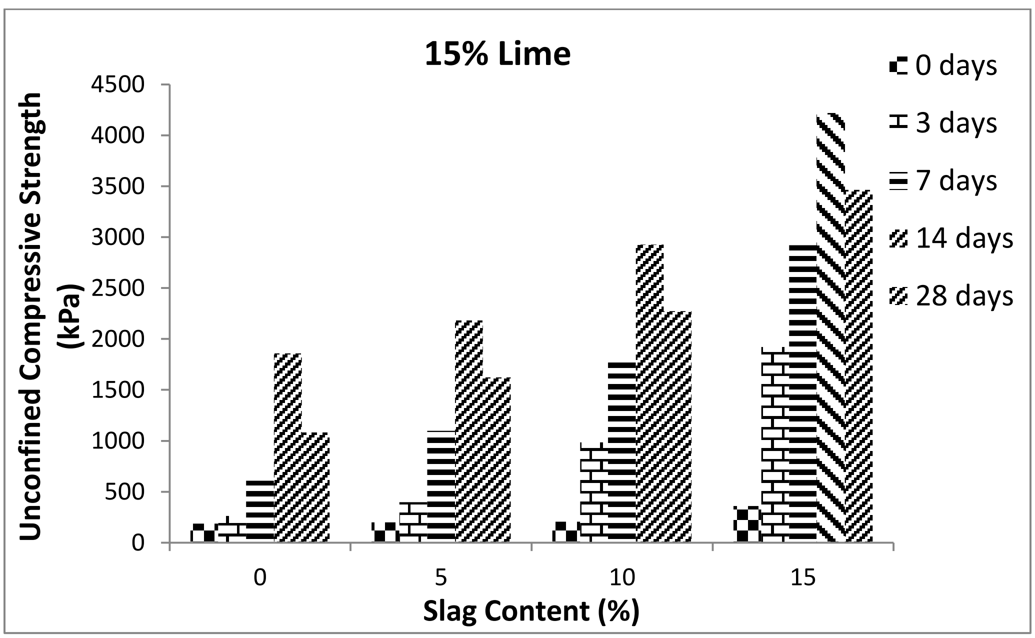

Fig 4.7 (v): Variation in UCS of samples with slag content at 15% lime content

With an increment in slag content, the pond samples showed an increment in strength when mixed with varying percentages of slag and lime. The strength of the UCS samples immediately showed an increase from 38.2 kPa to 59.05 kPa for the percentage varying of slag from no slag to 15% slag. When the samples are cured at the constant temperature of 27^0C for more days, the strength increased from 59.05 kPa to 688.8 kPa for 15% slag added to pond ash immediately to 28 days curing. The deviation of the strength the samples are studied and are given in fig 4.8 (i), (ii), (iii), (iv), (v) at 0, 3, 7, 14 and 28 days of curing period respectively.

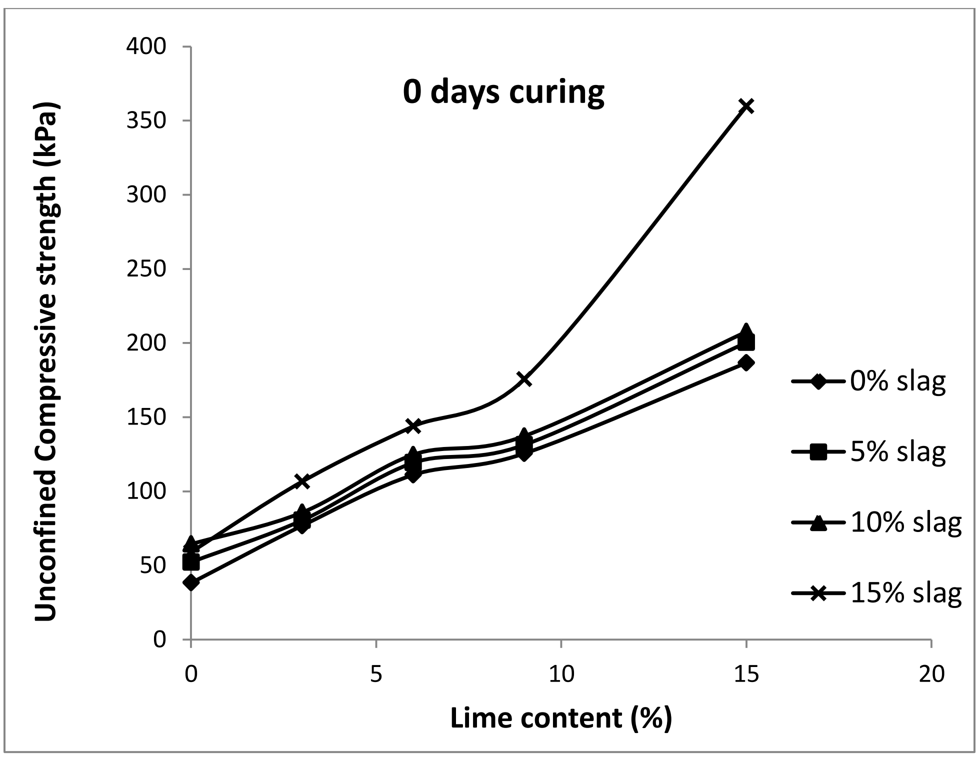

Fig 4.8 (i): Variation in UCS of samples with lime content after 0 days curing

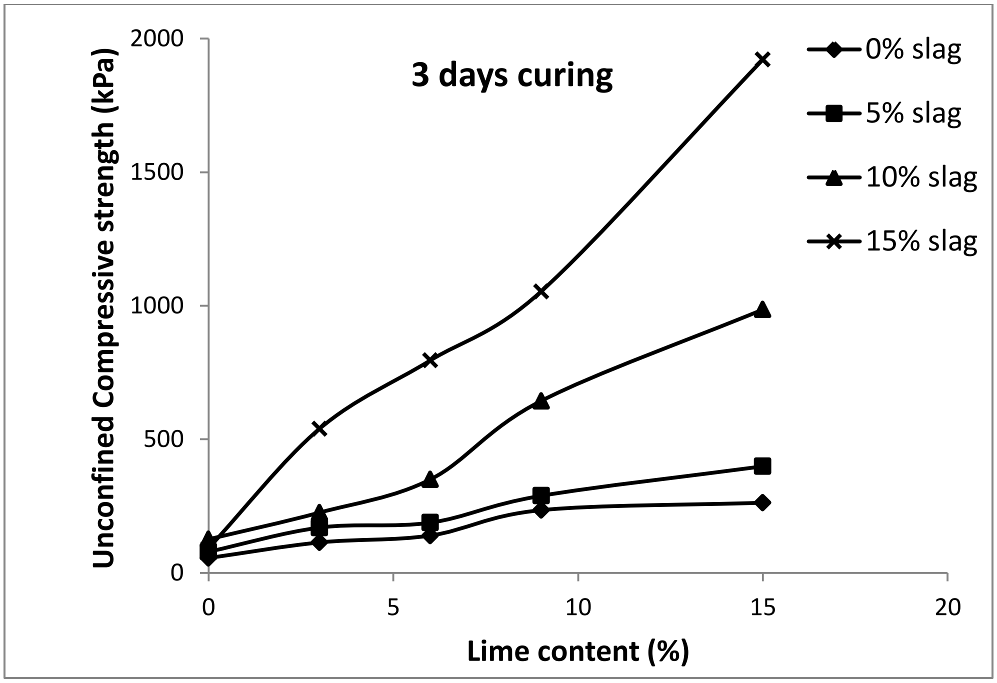

Fig 4.8 (ii): Variation in UCS of samples with lime content after 3 days curing

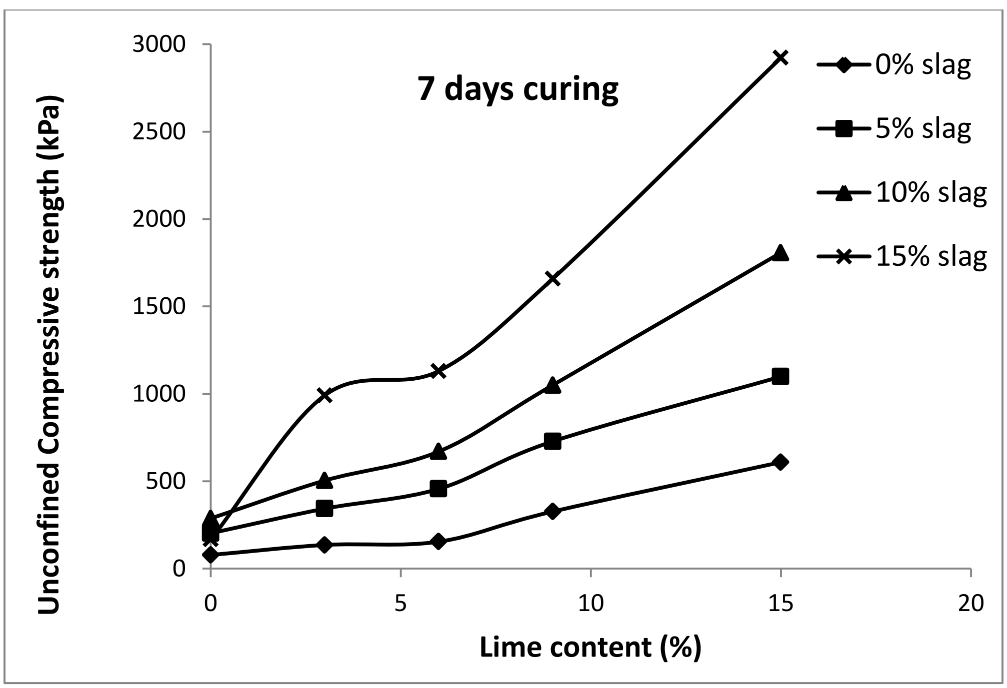

Fig 4.8 (iii): Variation in UCS of samples with lime content after 7 days curing

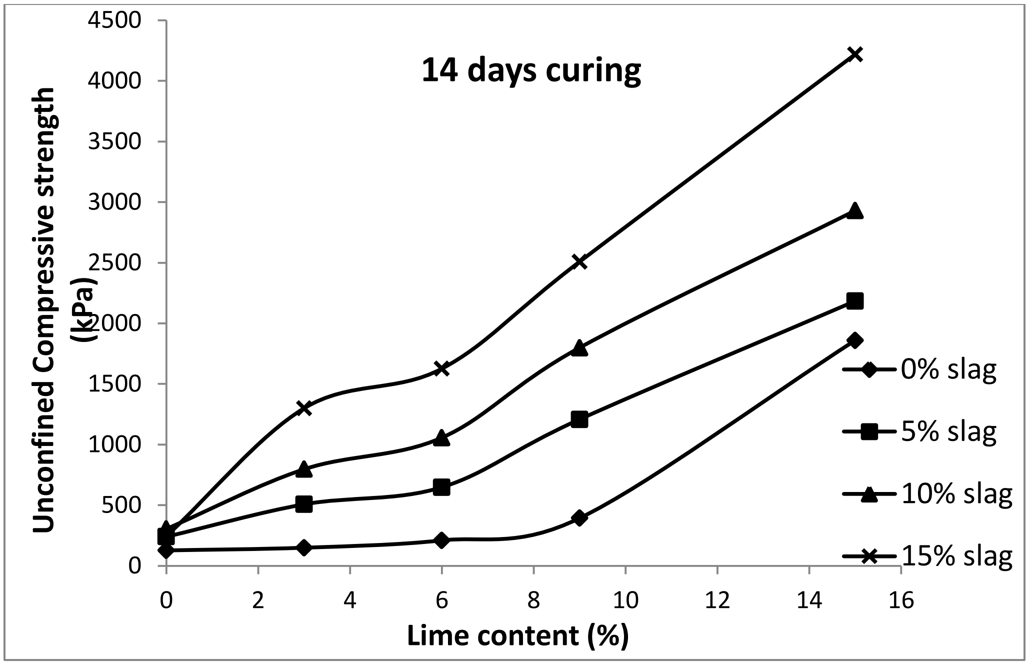

Fig 4.8 (iv): Variation in UCS of samples with lime content after 14 days curing

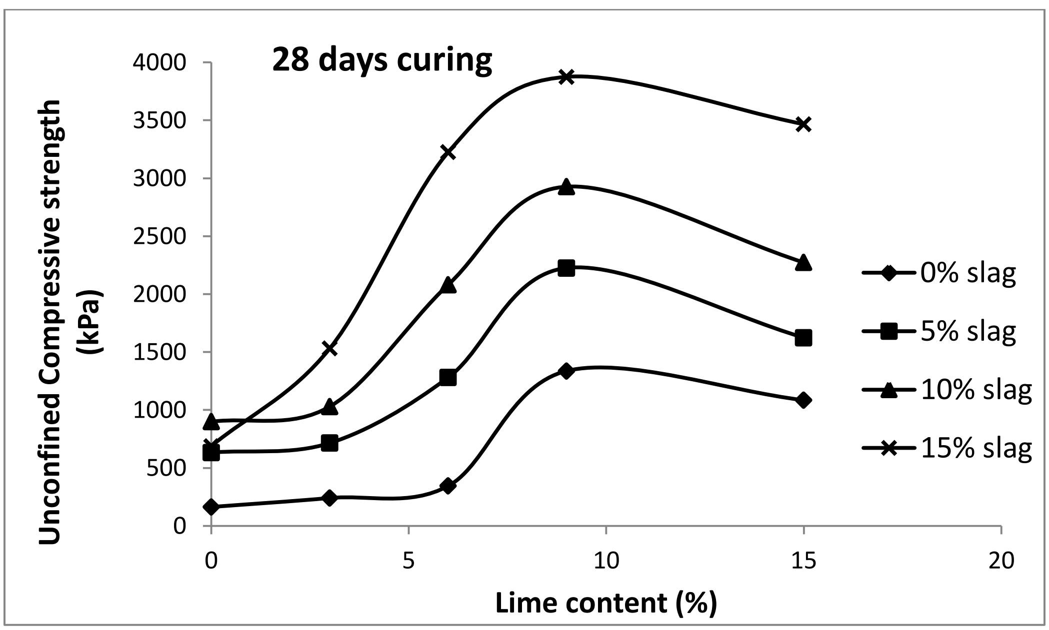

Fig 4.8 (v): Variation in UCS of samples with lime content after 28 days curing

4.3.3 Hydraulic conductivity of samples

The constant head permeability tests are conducted for determining hydraulic conductivity of the pond ash samples treated with lime and slag in different percentages. The permeability of the samples is determined at curing periods of 0, 7, 14 and 28 days. The effect of lime and slag content on conductivity of pond ash is determined and the results thus evaluated are represented in fig 4.9. (i), (ii), (iii), (iv) for immediate, 7, 14 and 28 days of curing. It was observed that with an increment in lime content from 0% to 15%, the permeability decreases from $10.1*10^{-5}$ cm/sec to $9.21*10^{-5}$ cm/sec.

The pozzolonic reaction of the lime with pond ash and slag results in gel formation. The capillary pores and the pore spaces are clogged due to the formation of gel in the void spaces. This resists the water flow as water cannot move through the gel pores. As a result of gel formation and clogging of pore spores, the permeability of the pond ash samples decreases.

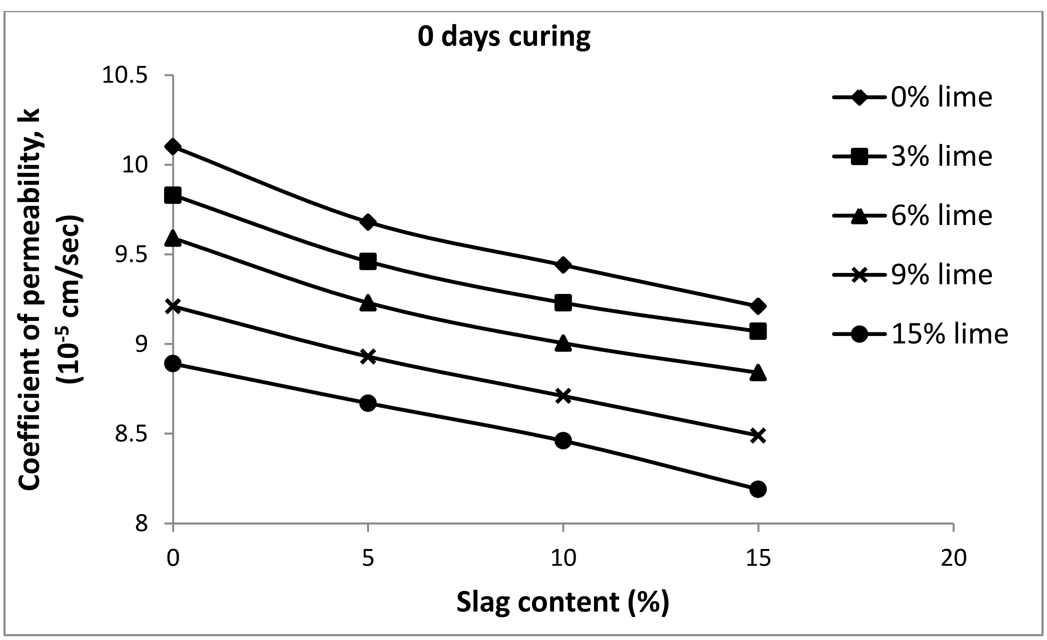

Fig 4.9 (i): Variation of coefficient of permeability of pond ash at different percentages of lime and slag after 0 days of curing

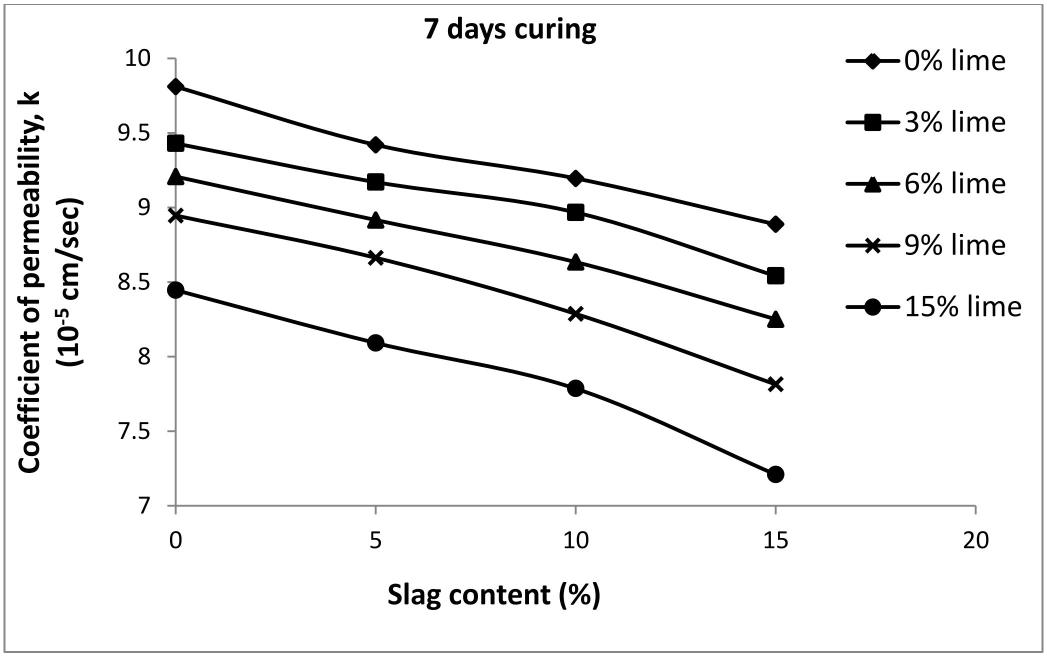

Fig 4.9 (ii): Variation of coefficient of permeability of pond ash at different percentages of lime and slag after 7 days of curing

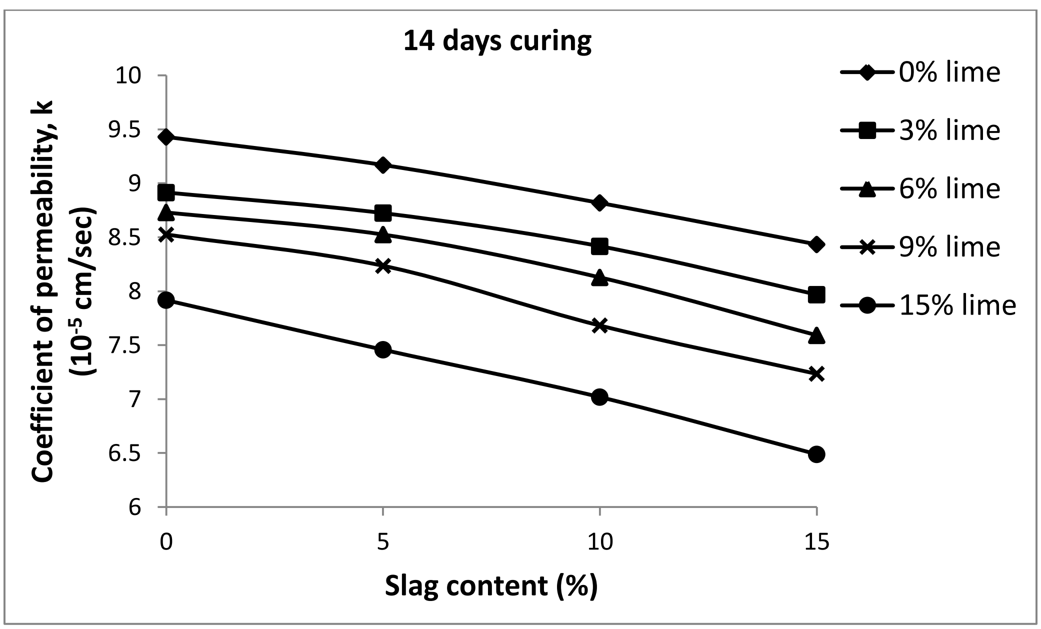

Fig 4.9 (iii): Variation of coefficient of permeability of pond ash at different percentages of lime and slag after 14 days of curing

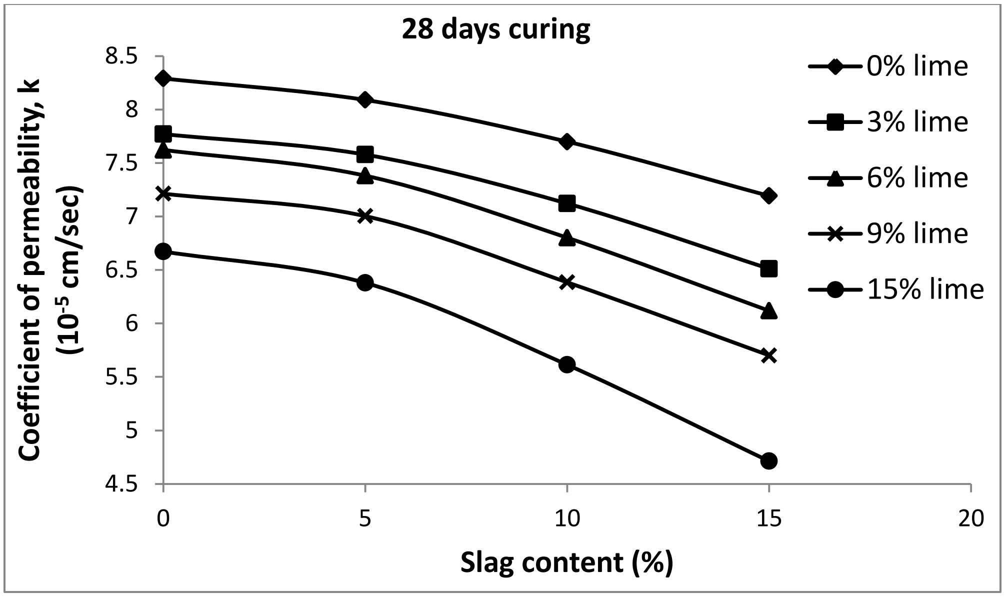

Fig 4.9 (iv): Variation of coefficient of permeability of pond ash at different percentages of lime and slag after 28 days of curing

With an increase in slag and lime content, the pozzolonic reaction increases which ultimately results in the void spaces getting fully clogged with gel formed in the reaction. As a result, the space available for the free movement of water decreases. Hence the permeability of the pond ash samples decreases with curing period.

4.4 Determination of optimum percentages of lime and slag

From the above results obtained it was noticed that when lime and slag content are increased, the unconfined compressive strength increases and the permeability decreases. Therefore to obtain the optimum percentage of lime and slag content in pond ash which would give the highest strength and lowest permeability which are considered as desired properties, varied percentages of slag (0, 5, 10, 15, 30, 50, 70, 100%) are combined with lowest percentage (3%) and highest percentage (15%) of lime and the strength and permeability of the samples are determined.

4.4.1 Light compaction test

The light compaction test is conducted and maximum dry density and optimum moisture content are determined for the pond ash samples at various percentages of slag at 3% and 15% lime content. The values of MDD and OMC of these samples are evaluated and are tabulated in table 4.1 and table 4.2 respectively.

Table 4.1: MDD of samples at various percentages of slag and 3% or 15% lime content.

Slag (%)	Lime (%)	
	3	15
0	1.22	1.296
5	1.256	1.332
10	1.29	1.348
15	1.31	1.363
30	1.378	1.474
50	1.548	1.625
70	1.629	1.761
100	1.82	1.82

Table 4.2: OMC of pond ash samples at various percentages of slag and 3% or 15% lime content.

Slag (%)	Lime (%)	
	3	15
0	24	21
5	22	19
10	21	18
15	21	18
30	20	18
50	16	15
70	14	14
100	13	13

With an increase in slag content up to 100%, the maximum dry density is observed to increase and optimum moisture content to decrease for pond ash samples at both percentages of lime content, at very low percentage and high percentage of lime with varied percentages of slag. The variation of MDD and OMC of the pond ash samples at 3% lime content and 15% lime content at different percentages of slag are shown in fig 4.10 (i) and (ii) respectively.

The dry density of the samples increased from 1.22 g/cc to 1.82 g/cc and water content decreased from 24% to 13% for 3% lime content whereas for 15 % lime content, the dry density increased from 1.296 g/cc to 1.82 g/cc and water content decreased from 21% to 13%. With an increase in slag content, more void spaces are filled with lime which increases the maximum dry density. As the pore spaces are filled with lime and due to differential structure of slag, the optimum moisture content decreases.

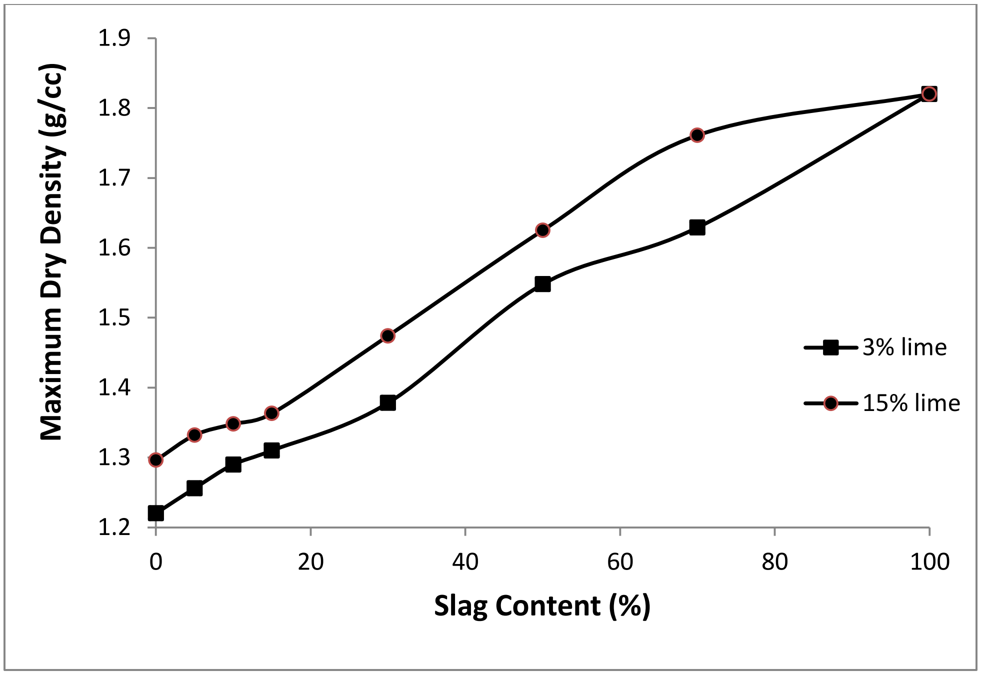

Fig 4.10 (i) Variation of MDD of pond ash samples at different percentages of slag at 3% lime and 15% lime.

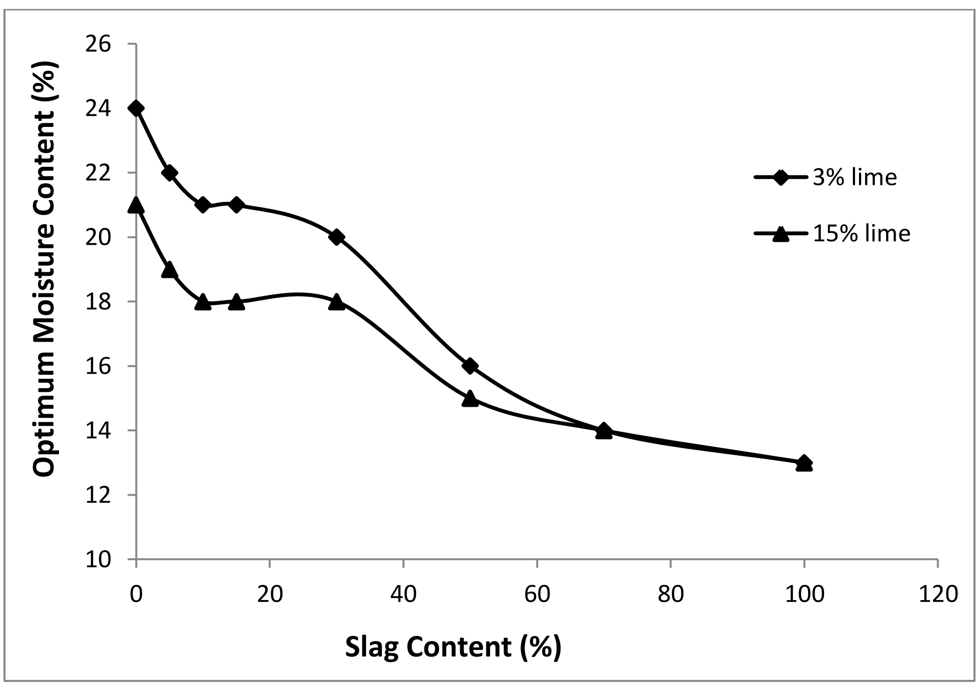

Fig 4.10 (ii) Variation of OMC of pond ash samples at various percentages of slag at 3% lime and 15% lime.

4.4.2 Unconfined Compressive Strength

The unconfined compressive strength is determined for pond ash samples for varying percentages of slag at 3% and 15% lime contents. The maximum dry density and optimum moisture content determined by light compaction tests are used for making the UCS samples. The samples with different percentages of slag (0, 5, 10, 15, 30, 50, 70 and 100) are made in 3% lime and 15% lime. The variation of strength of pond ash samples with varied percentages of slag at two different lime percentages are given in table 4.3.

Table 4.3 Unconfined Compressive Strength of pond ash samples at 3% and 15% lime at different curing periods

Slag (%)	Lime (%)					
	7 days		14 days		28 days	
	3%	15%	3%	15%	3%	15%
0	135.72	609.03	149.1	1859.23	240.48	1187.34
5	343.33	1798.57	507.06	2183.25	937.89	1624.47
10	504.21	2209.13	604.35	2729.17	1210.65	1933.29
15	991.55	2922.18	1399.2	3018.55	1531.36	2066.55
30	872.7	2877.1	1775.36	3716.15	2652.57	2433.06
50	711.72	2590.4	2106.76	4007.19	3174.15	2752.9
70	583.5	1542.5	1441.73	3757.43	2204.79	3984.56
100	171.69	171.69	50.09	50.09	12.59	12.59

The pond ash samples with 3% lime, 15% lime reached optimum strength at different percentages of slag for various curing period. The strength of pond ash with varied percentages of slag and 3% and 15% lime for curing periods of 7, 14 and 28 days are represented in fig 4.11. (i) and fig 4.11 (ii) respectively.

At same percentage of lime, when slag content is increased in pond ash samples the lime reacts with the amorphous silica present in slag upto optimum point. Beyond that point, there will be no availability of lime for amorphous silica reaction which results in decrease of strength of UCS samples.

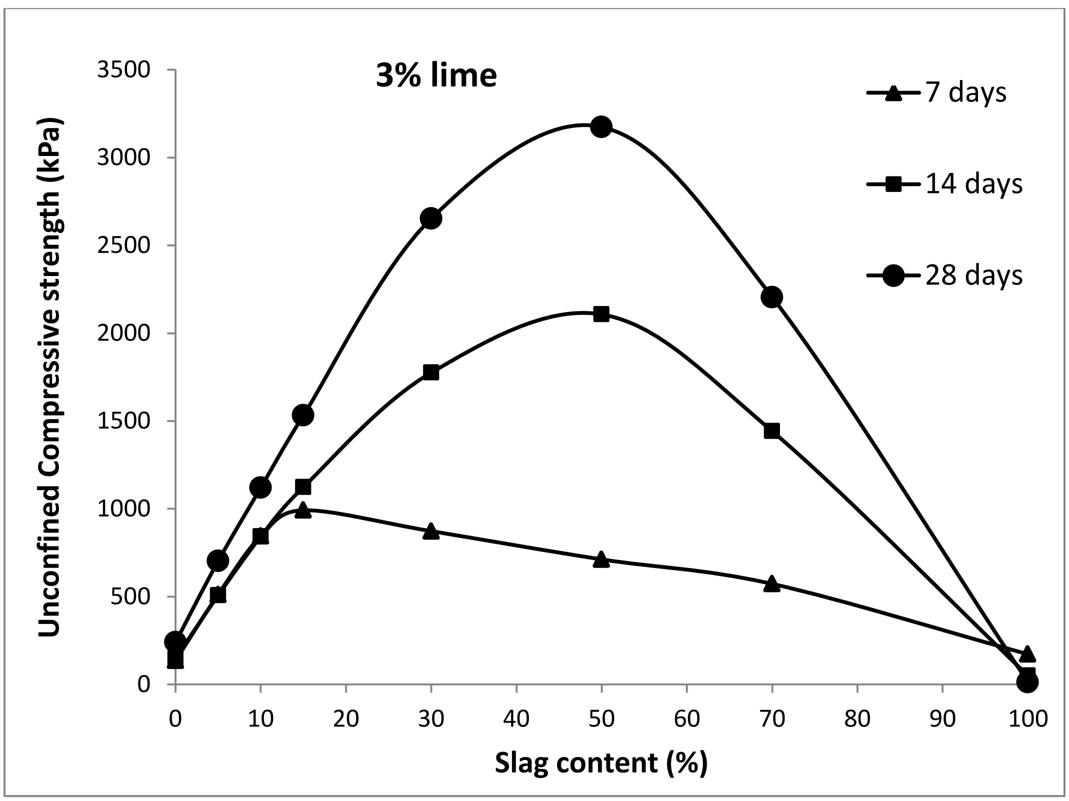

Fig 4.11 (i) Variation of UCS of pond ash samples at varied percentages of slag at 3% lime content.

When the lime content added as stabilizer to the pond ash samples is increased from 3% to 15%, more lime will be available for the amorphous silica reaction with slag. Hence the strength of the UCS samples is higher for samples with 15% lime than compared to 3% lime.

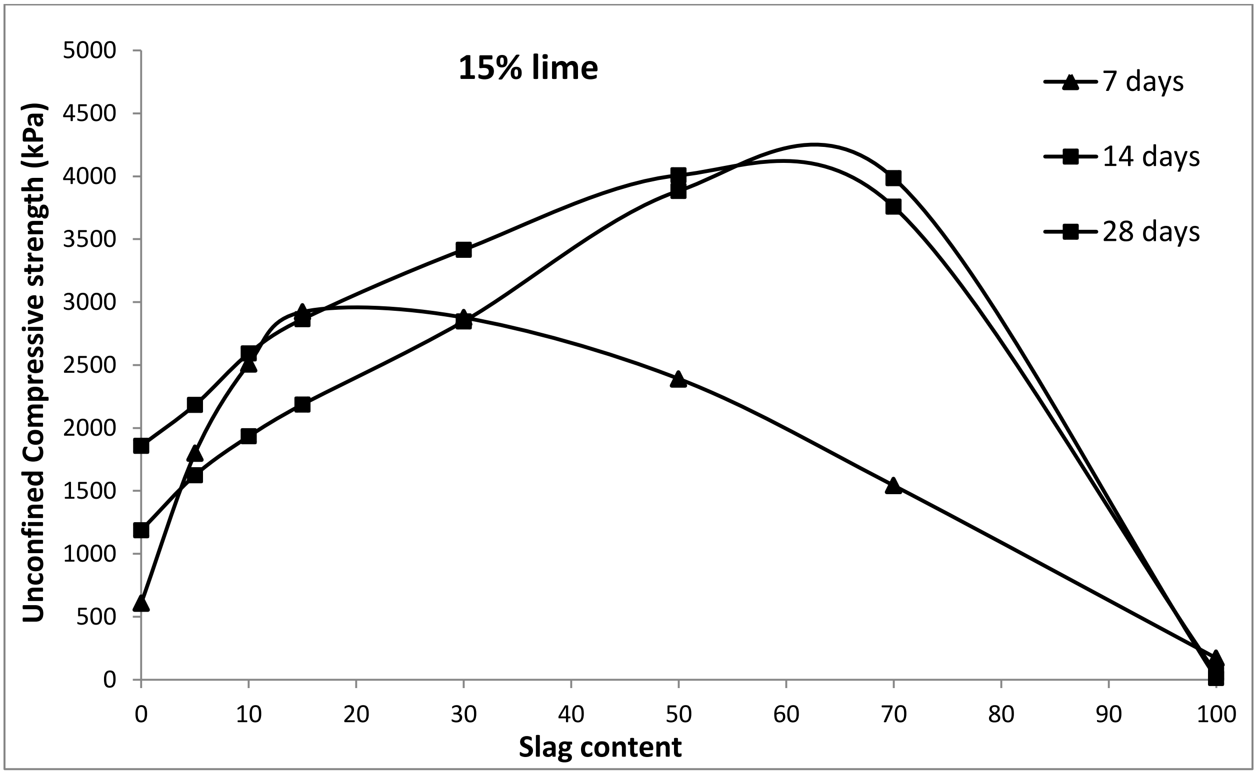

Fig 4.11 (ii) Variation of UCS of pond ash samples at varied percentages of slag at 15% lime content.

From the above figures, the optimum percentages of lime and slag which would attain maximum strength are calculated and are given in table 4.4. The percentages of slag required to attain the maximum strength varies with the curing period. It is due to the improvement of strength due to pozzolonic reaction of lime with pond ash and slag. There is no further improvement in strength upon the optimum point as the lime content taken will not be sufficient

Table 4.4 Optimum percentages of slag required for various curing periods at 3% and 15% lime contents.

Curing period (days)	Lime (%)	
	3	15
7	17	20
14	48	50
28	48	67

The curing period is found to have great effect on the strength characteristics of pond ash samples. When the opted curing period is increased, the resulted strength of the samples increased. This is due to increase in pozzolonic reaction of lime with slag and pond ash with the elapsed time. The influence of adopted curing period on unconfined compressive strength is studied and is represented in the fig 4.12 (i), (ii) and (iii) for samples with 3% lime and 15% lime in pond ash with varied percentages of lime.

The pond ash samples with 15% lime are observed to have less strength for 28 days as compared to 14 days. This may be due to the achievement of optimum strength of lime stabilized pond ash before 28 days. The MgO present in lime is responsible for slow phase reaction due to hydration. The micro cracks are developed due to hydration beyond 14 days which results in reduced strength for lime content of 15% .

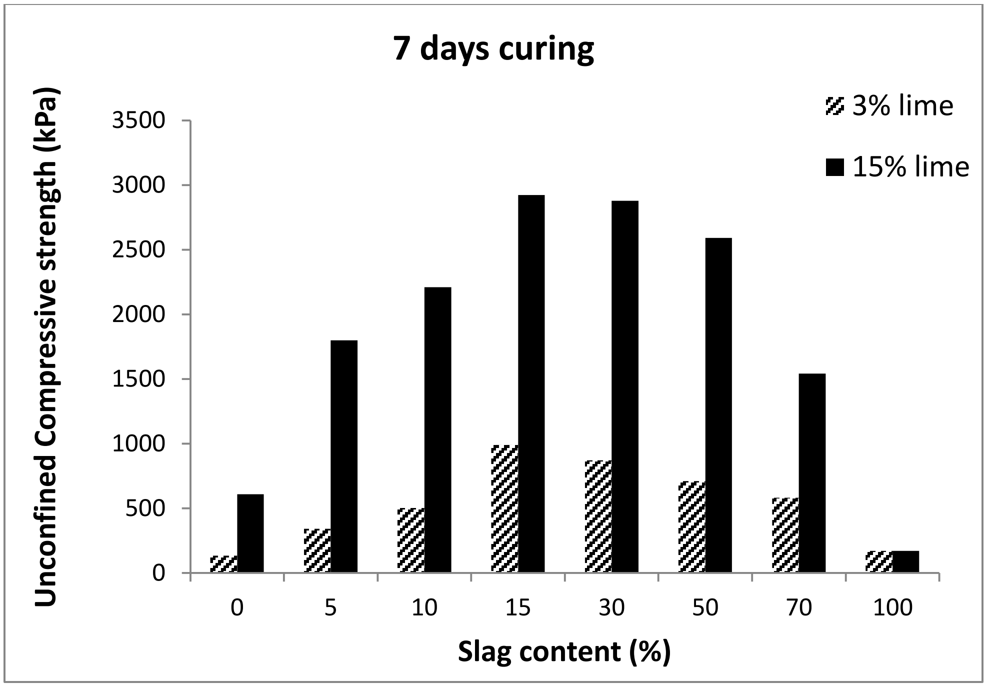

Fig 4.12 (i): Variation of UCS with slag content at 3% and 15% lime content after 7 days curing

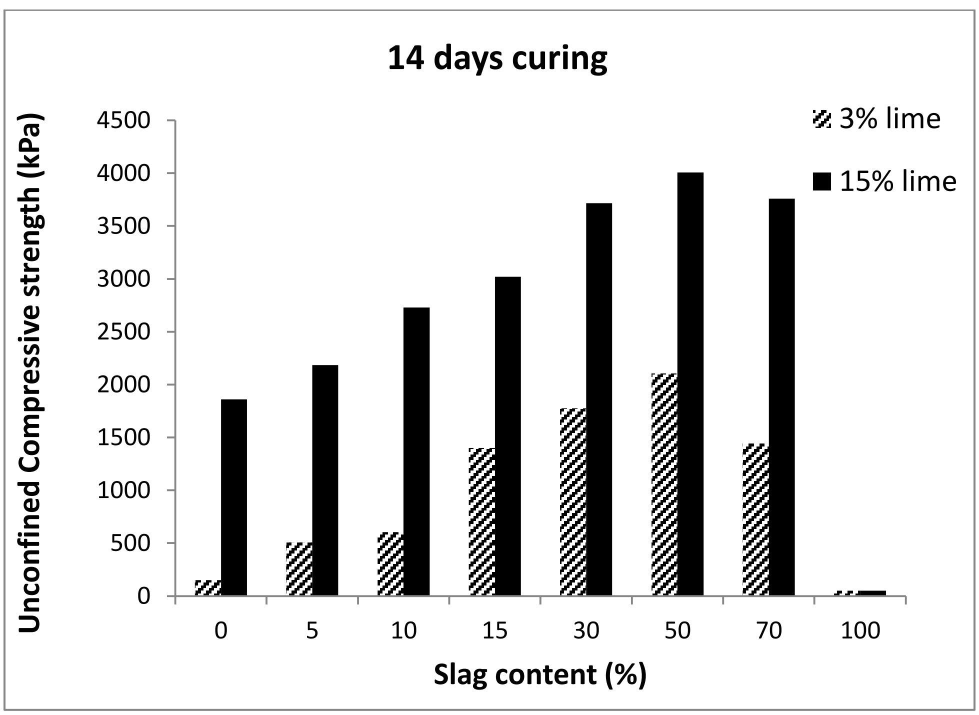

Fig 4.12 (ii): Variation of UCS with slag content at 3% and 15% lime content after 14 days curing

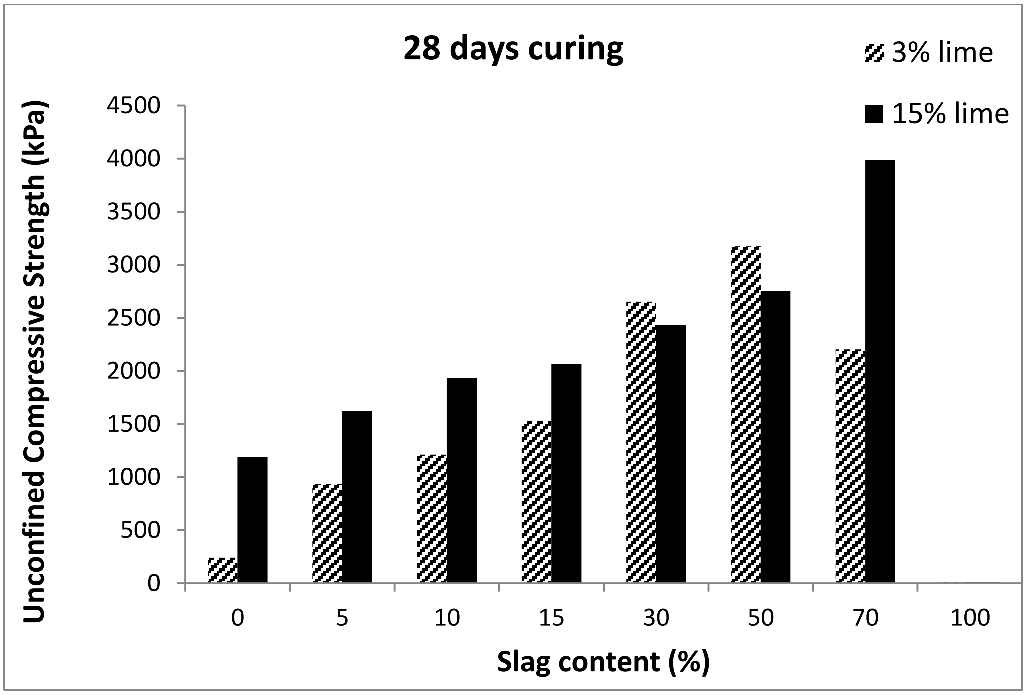

Fig 4.12 (iii): Variation of UCS with slag content at 3% and 15% lime content after 28 days curing

CHAPTER-5

CONCLUSIONS

5.1 Conclusions

Experiments are conducted to determine the strength and hydraulic properties of lime stabilized pond ash with slag as admixture. The effect of lime and slag content and corresponding curing period on the strength and hydraulic properties are analyzed and studied. Based on the obtained results, the following main conclusions are drawn at:

- The grain size analysis curve of pond ash shows uniform graded particles which have most of the particles lying in the range of fine sand to silt size. The percentage of pond ash passing through 75μ sieve was found to be 88%. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) for pond ash was found to be 5.67 & 1.25 respectively, which indicates a uniformly graded material.
- The Maximum Dry Density of pond ash varies from 1.185g/cc to 1.296g/cc and the Optimum Moisture Content decreased from 27% to 21% for increase of lime content from 0 to 15%. With an lime content is increased, the MDD value increases and OMC value decreases as the lime added undergoes colloidal reaction with the pond ash and slag. The pore spaces of slag are filled with lime which results in increased dry density and decreased water content.
- With an increase in slag content from 0 to 15% in pond ash, the Maximum Dry Density was observed to increase from 1.185 g/cc to 1.283 g/cc and Optimum Moisture Content

decreased from 27% to 23%. With an increase in slag content, more slag will be available for colloidal formation which results in increased MDD values and decreased OMC values.

- The dry density of only pond ash was observed to be 1.185 g/cc which increased to 1.363 g/cc at 15% of lime and 15% of slag contents in pond ash. With increased lime and slag contents in pond ash, the pore spaces of pond ash are mostly filled with lime and slag increasing the colloidal formation thereby increasing MDD and decreasing OMC values gradually.
- When the lime content is increased, the unconfined compressive strength of pond ash samples increases due to pozzolonic reaction. The strength of the pond ash samples increased from 38.2 kPa to 186.6 kPa with no lime to 15% lime respectively.
- The immediate strength of pond ash samples increased with an increase of slag content up to 10%. The strength decreased from 64.37 kPa to 59.05 kPa from 10% slag to 15% slag in pond ash samples due to the non-reactive silica available beyond 10%.
- With an increase in slag content, the strength of pond ash samples increases due to the increased availability of silica for amorphous silica reaction. The strength of the UCS samples immediately showed an increase from 38.2 kPa to 59.05 kPa for the percentage varying of slag from no slag to 15% slag.
- The silica present in slag reacts with the lime added to pond ash resulting in pozzolonic reaction. Hence with a slight increase in lime and slag content, the strength increases in pond ash samples. The strength increased from 38.2 kPa to 359.55 kPa for only pond ash to 15% slag and 15% lime added to pond ash samples.

- The strength of the pond ash samples increased when the curing period is increased. The unconfined compressive strength increased from 38.2 kPa to 163 kPa for pond ash for 0 days curing to 28 days curing. With an increase in curing period, the pozzolonic reaction increases which results in increase in strength.
- After 14 days of curing, there is no observed strength for pond ash combined with 15% lime at different percentages of slag. When the lime content is increased to 15%, micro cracks are developed due to slow phase hydration which results in decrease in strength beyond 14 days of curing.
- The strength of pond ash samples with different lime and slag percentages increases when the curing period adopted is increased.
- The permeability of pond ash samples showed a decrement when the lime and slag percentages are increased. Due to the pozzolonic reaction between lime, slag and pond ash, gel formation occurs which results in clogging of pore spaces. There arises the difficulty in passage of water through the pore spaces thereby decreasing the permeability.
- It was noticed that with an increase in lime content from 0% to 15%, the permeability decreases from $10.1*10^{-5}$ cm/sec to $9.21*10^{-5}$ cm/sec.
- The permeability of the pond ash samples slightly showed a decrement with an increase in curing period adopted. The formation of gel between the pore spaces increases when the curing period is increased thereby clogging most of the pores which results in decreased permeability of the samples.

- The optimum percentage of slag required for attaining maximum strength at 3% lime and 15% lime depends upon the availability of lime and slag for amorphous silica reaction resulting in pozzolonic reaction.
- The optimum percentage of slag required for 15% lime is higher than compared to the requirement of 3% lime. With an increase in lime content, more quantity of lime is readily available for pozzolonic reaction resulting in high strength.
- The optimum slag content required varies with the curing period adopted for the samples. It depends upon the pozzolonic reaction of lime with slag and pond ash in the adopted curing period.
- For 3% lime, the optimum percentage of slag required for obtaining maximum strength is 15%, 56%, 17%, 48% and 48% of curing period for immediate, 7, 14and 28 days respectively.
- For 15% lime, the optimum percentage of slag required for obtaining maximum strength is 30%, 53%, 20%, 50% and 67% of curing period for immediate, 7, 14 and 28 days and 28 days respectively.

5.2 Future Work

Some more important aspects have to be considered for effective utilization of pond ash in various fields.

- Effect of mineral and chemical admixtures like silica fume, glass powder etc.
- Durability test to study the durability aspect.
- Behaviors of stabilized pond ash under repeated loading.
- Compressibility and Consolidation characteristics of compacted pond ash.

- Studies on morphology and microstructure and relate this to the obtained strength.
- Effect of lime in controlling the leachate quality coming out of pond ash.
- Liquefaction susceptibility of pond ash.

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